Saskatchewan Agriculture, Food and Rural Revitalization

ADF

AGRICULTURE DEVELOPMENT FUND

FINAL REPORT

20010276

MONITORING THE LONG-TERM EFFECTS OF REPEATED SWINE MANURE APPLICATIONS IN CROP PRODUCTION, SOIL AND ENVIRONMENTAL QUALITY IN SASKATCHEWAN

Funded by: The Agriculture Development Fund

March, 2005

Prepared by: University of Saskatchewan

105-04666/

Monitoring the Long-Term Effects of Repeated Manure Applications On Crop Production, Soil and Environmental Quality In Saskatchewan

FINAL REPORT
Project no: 20010276
SaskPork Project no: 2001-10

January 2005

Abstract

The objective of the research was to determine the influence of repeated applications of manure on crop production, soil and environmental quality as revealed in four field trials located at Dixon, Melfort, Plenty and Riverhurst SK. Soil nutrients, crop yield and quality, trace metals, soil salinity, sodicity and structure, soil organic matter and biochemical attributes were measured in soils and plants from the research trials with a history of five to eight years of manure addition. Application of swine and cattle manure at agronomic rates in balance with that removed by the crops over time resulted in good crop yield responses while avoiding the accumulation of nutrients, trace metals and salts. Manures tended to promote increased soil organic matter content, especially cattle manure and contributed to improved soil physical structure and water infiltration. Injection of liquid manure gave superior agronomic response and nutrient recovery than surface application. Improved crop response and utilization of applied manure nutrients can be achieved by supplementing with commercial fertilizer to achieve the desired balance of available nutrients. Repeated manure applications to Saskatchewan soils are sustainable and environmentally sound, provided that the appropriate agronomic rate and method of placement are used.

Dr. Jeff Schoenau, M. Grevers, M. Japp, T. King, S. Lipoth, P. Qian, C. Stumborg
Department of Soil Science, College of Agriculture, University of Saskatchewan, 51 Campus Drive, Saskatoon SK S7N 5A8 email:schoenau@sask.usask.ca

Executive Summary

After five to eight years of manure application at four SK sites (Dixon, Melfort, Plenty and Riverhurst) using different rates, sequences and methods of application, the results indicate that manure that is applied at rates that are in balance with crop removal and uptake over time is a sustainable management practice. In-soil placement of liquid swine manure by injection produces superior crop yield and nutrient recovery compared to surface application while minimizing odors. Additions of swine manure equivalent to about 100 lbs N/acre annually is capable of maximizing crop production with no apparent excess nutrient accumulation, toxicity or losses. Larger single applications made once every second or third year also do not appear to be associated with nutrient loading or large migration of nutrients out of the soil profile, but risk of nutrient loss or crop injury is greater in the year of application with a single high rate and the residual effects appear to have diminished significantly by the third year. Large additions made every year, e.g. 10,000 plus gallons per acre per year, result in excessive accumulations of nitrate and evidence of leaching below the rooting zone, as well as build-up of labile, potentially mobile phosphorus. For cattle manure, the build-up of excessive nitrates at high rates of application after eight years was not apparent, reflecting the slow release of available N from the organic N forms in the manure. However, labile soil phosphorus was found to increase more rapidly in the cattle manure treatments than in swine manured soils and should be monitored closely.

As manure often does not have the appropriate balance of available nutrients required by plants, there can be benefits from supplementing manure with commercial fertilizer application. Nutrient balances, especially N:S and N:P following manure application must be considered. No response to supplemental P fertilization was observed in the trials at Dixon in 2003 despite low amounts of P added as manure, but responses were observed in 2004 on the agronomic rate treatments. Application of low P content swine manure at agronomic rates to supply N to crops could show response to additional fertilizer P for some crops in some years. However, this would not be the case where manure was applied at high rates as there is evidence for P build-up when swine manure is over-applied. Substantial responses to S fertilizer applied in 2002 were observed with canola in 2003 on manured plots on a sulfur-deficient soil at Melfort, but no responses were observed with oats in 2004, likely due to the diminished residual effect of the sulfur fertilizer application in 2002. Special attention should be given to sulfur when growing crops on S deficient soils that have received high rates of swine manure in the past, as nitrogen may carryover into subsequent years but the sulfur added as manure may have been all used up by the crop in the year of application. Residual effects of manure applications made in past years on increasing availability of nutrients in the current year are very apparent, especially with cattle manure. These residual effects should be taken into consideration in manure nutrient management planning.

Applications of manure increased nitrogen, phosphorus and sulfur concentrations and uptake by the crops grown. In general, the cereal and oilseed crops grown in 2003 and 2004: wheat, canola, oats responded well to manure application in increased yield and protein content. The combination of manure with additional commercial fertilizer

applied appeared to result in some reductions in potato tuber yield in irrigated potatoes that may be associated with excess nitrogen and should be explored further. Canary seed yield was not as responsive to manure as the other crops. At the Plenty site, accumulations of nutrient in the soil were highest, reflecting three years of low yield due to drought and insect accumulations. These results indicate the importance of matching manure nutrient application rate to crop growth and nutrient removal potential.

After five to eight years of repeated manure application, the accumulation of trace metals in the manured soils appears to be limited to some relatively small increases in labile copper and zinc. There was no evidence for accumulation or toxicity of non-functional trace metals like mercury or arsenic in soils or plants.

In the field, early crop growth and development was not significantly influenced by a history of repeated annual applications of swine manure, especially at agronomic rates. However, care must be taken when seeding crops into soils that have received high rates of liquid manure that year and in which there has been limited leaching, as salts and ammonium from the manure may be present in the seeding zone that could interfere with germination and early plant development, especially under dry conditions.

Soils from the trials with a history of five to eight annual manure applications showed no apparent increases in salinity or sodicity associated with the manure applications at either low or high rates. Consistent with this was the observation that surface crusting was either not affected or reduced with manure application and that water infiltration was not affected or sometimes increased in the manured soils. In general, repeated manure application at agronomic rates was found to have no detrimental impact on early crop growth or soil physical properties.

Increases in soil organic matter content associated with five to eight years of annual swine manure additions are not large, and are mainly related to enhanced crop growth and residue input, that shows up as increased light fraction organic carbon. Compared to solid manures, liquid swine manure adds relatively little organic matter directly. As the nutrients will stimulate microbial activity and enhance decomposition, there may a counteracting effect and it may take many years before significant increases are observed. Manure applications at agronomic rates generally had no impact on microbial enzyme activity or else they increased enzyme activity in the soil that would contribute to higher rates of nutrient recycling.

In general, the application of manure fertilizer increases the plant availability of some of the metals and has no effect on others. AB-DTPA extractable soil fractions and/or plant tissue content of copper, zinc, and cadmium may increase significantly with increasing manure or N fertilizer rates, but the increases are not large. Selenium, arsenic, and mercury plant availability generally remain unchanged by increasing manure fertilizer rates. Manure does not appear to enhance soil crust formation or interfere with emergence and early plant development, nor is it associated with significant increases in salinity, sodicity or soil strength. Repeated additions of swine manure had variable effects on soil organic carbon in surface soils. Soils low in soil organic matter and of

high clay content showed large, significant increases while soils high in organic matter did not show a significant effect. In some soils urea or swine manure addition may enhance the decomposition of soil organic matter. Increases in organic matter with cattle manure addition are attributed to direct addition of organic matter in manure. Increases in light fraction organic matter act as substrate for microorganisms to convert into stable humus.

Overall, it is concluded that annual applications of manure made for five to eight years on these soils at agronomic rates in balance with crop nutrient removal greatly enhanced crop production while maintaining or improving soil and environmental quality. Agronomic, sustainable rates of manure differ depending on manure and soil nutrient availability, crops grown and environmental conditions, and should be assessed using soil, manure testing with corresponding nutrient recommendations. The soil-climatic conditions are especially important as these influence crop nutrient demand. For example, using generalizations based on the results of this study, agronomic rates of swine manure may be considered to be ~70 to 120 kg N / ha added each year or 140 to 240 kg N / ha added every second year. Rates on the higher side are appropriate in more moist climatic regions such as the Black soil zone where crop yield potential is high, while lower rates are more suitable in drier regions and under drought and other causes of crop failure that restrict crop nutrient removal in one or more years as experienced at the Plenty site.

Technical Report

This report covers field and laboratory research work conducted by the University of Saskatchewan Soil Science Department at four long-term research sites in Saskatchewan. Dixon, Melfort, Plenty and Riverhurst in 2003 and 2004. Results of research work conducted from 1998 to 2002 are found in previous AFIF, ADF and SaskPork reports as well as scientific publications and the Soils and Crops Workshop Proceedings. With funding from ADF and SaskPork, research work will continue for another two years (2005 and 2006) at these sites.

Objective: To reveal the effect of repeated (five to eight years) manure applications on crop growth (yield, protein) , soil and environmental quality (nutrients, metals, salts, structure, organic matter, biochemistry) under Saskatchewan conditions.

Field Site Description and Experimental Design

This report covers field and laboratory activities in 2003 and 2004. The following is a description of the four field sites and experimental design.

Manure Application and Sampling: Liquid swine manure was applied using low disturbance injection coulters with the PAMI Effluent Injection truck while the cattle manure was applied by hand and incorporated using a rotary tiller. At each site each

year, approximately six samples of manure were collected from the applicator during application to the plots. The manure samples were chilled and then shipped to the lab where they were frozen until analysis.

Dixon

Legal Location: NW21-37-23-W2

Cudworth Association: loamy Black Chernozemic soil on silty lacustrine parent material

History:
1997 – Canola
1998 – Wheat
1999 – Barley
2000 – Canola
2001 – Wheat
2002 – Flax (drought)
2003 – Barley
2004 – Canola (frost)

Special Notes: In 2002, 2003 and 2004, 15kg P_2O_5/ha of ammonium phosphate (12-51-0) was banded prior to seeding at one end of each 30m X 6m swine manure and urea plot to provide no P and P fertilized sub-plots.

Experimental Design: Randomized complete block design with four replications. Tests plots are 30m X 6m.

Manure Application: Liquid swine manure effluent from a nearby earthen storage pit was injected 10-13 cm deep into test plots using a low disturbance injector each year for 8 years (1997-2004). Cattle manure was broadcast by hand and incorporated (1997-2004).

Treatments (hog):

-3 rates of injected effluent:
-3,300 gpa 1X including injected, broadcast & incorp., 12" and 24" injector spacing
-6,600 gpa 2X
-13,200 gpa 4X

-Applied in different sequences: annually, semi-annually, once every 3 yrs
-Broadcast and Incorporated effluent (3,300 gpa)
-Banded Urea (46-0-0) (low 1X 50, medium 2X 100 and high 4X 200 kg N/ha)
-Disturbed Check Strips

Treatments (cattle):

-3 rates of broadcast and incorporated manure:
-7.6 tonnes/ha
-15.2 tonnes/ha
-30.4 tonnes/ha

Applied in different sequences, plus broadcast and 24 hour delayed incorp treatment, and three urea treatments same as for swine manure trials.

-Disturbed Check Strips

Melfort

Legal Location: SW26-44-18-W2

Melfort Association/Kamsack Association loamy Grey-Black Chernozemic soil

History: 2000 – Wheat

2001 – Canola
2002 – Oats
2003 – Canola
2004 – Oats (some frost)

Special Notes: In 2002 separate applications of elemental sulfur and sulfate at 40 kg S/ha were banded prior to seeding at one end of each 30m X 6m swine manure and urea plot to provide sub-plots of S fertilized (two forms of S).

Experimental Design: Randomized complete block design with four replications. Tests plots are 30m X 6m.

Manure Application: Liquid swine manure from a nearby earthen storage pit was injected 10-13 cm deep into test plots using a low disturbance injector each year for 5 years (2000-2004).

Treatments:

-3rates of injected effluent:
- 3000 gpa applied every year
-6000 gpa applied every second year
-9000 gpa applied every third year

-Urea (46-0-0) (80 kg N/ha) application
-Disturbed Check Strips

Plenty

Legal Location: SW5-33-18-W3

Regina Association: heavy clay-clay Dark Brown Chernozemic soil on clay lacustrine parent material

History: 1999 – Spring Wheat
2000 – Canary Seed
2001 – Spring Wheat
2002 – Crop Failure (drought)
2003 – Wheat
2004- Canary Seed

Special Notes: Frequent poor yields due to low moisture in NW SK over study period.

Experimental Design: Randomized complete block design with three replications. Tests plots are 30m X 6m.

Manure Application: Liquid swine manure from a nearby earthen storage pit was injected 10-13 cm deep into test plots using a low disturbance injector each year for 6 years (1999-2004).

Treatments:

2 rates of injected hog effluent applied in 6 sequences:
Low Rate: 5000 gpa first four years, then 3300 gpa for last two years
High Rate: 10000 gpa first four years, then 6600 gpa for last two years
Urea (46-0-0): (High rate 80 kg N/ha, Low rate 40 kg N/ha) application
Disturbed Check Strips

Riverhurst

Legal Location: SW20-24-5W3

Birsay Association: Sandy loam textured Brown Chernozemic soil on sandy glacio-lacustrine parent material

History: 1999 – Pinto Beans
2000 – Barley
2001 – Barley
2002 – Crop Failure (grasshoppers)
2003 – Wheat
2004 - Potatoes

Special Notes: Irrigated site (over 20 years)

Experimental Design: Randomized complete block design with three replications. Tests plots are 30m X 6m.

Manure Application: Liquid swine manure from a nearby earthen storage pit was injected 10-13 cm deep into test plots using a low disturbance injector each year for 6 years (1999-2004).

Treatments:

2 rates of injected hog effluent applied in 6 sequences:

Low Rate: 5000 gpa first four years, then 3300 gpa for last two years

High Rate: 10000 gpa first four years, then 6600 gpa for last two years

-Urea (46-0-0) (High rate 80 kg N/ha, Low rate 40 kg N/ha) application

-Disturbed Check Strip

Manure, Soil and Plant Analysis

Manure: Manure was sampled at the time of application, with about six samples of manure collected during application at each site. The manure samples were digested and analyzed for total nutrient content using inductively coupled plasma emission spectroscopy. Ammonium and nitrate (available) nitrogen forms in the manure, along with soluble phosphate were extracted with water and measured colorimetrically.

Soil: Soil samples were taken in the spring before seeding and again in the fall after harvest and before the fall manure application was made. Three cores were taken at random from each plot, with samples from each core bulked for a plot according to depth. Sampling was conducted with large diameter PVC cores to a 15 cm depth in the spring, and with a hydraulic punch truck coring unit to 60cm depth in fall of 2003 and to 120 cm depth where possible in the fall of 2004. Soil nutrient contents were analyzed using various techniques, including 2MKCl extraction and colorimetry for ammonium and nitrate, Kelowna, water and anion exchange membrane (AEM) extraction and colorimetry for P, atomic absorption and ICP for potassium and metals. Techniques for assessing physical properties are described in detail in part B, and include penetrometer assessments of soil strength, water infiltration using rainfall simulation, modulus of rupture for crusting. Soil organic matter was measured using automated combustion carbon analysis of whole soil and fractions while microbial enzyme activities were assessed using various enzyme assay techniques.

Plants: At harvest, square meter plant samples were taken from each plot so as to enable collection and analysis of both grain and straw. The samples were threshed and the grain and straw retained and ground. The ground plant samples were analyzed for nitrogen and

sulfur using a carbon, nitrogen sulfur analyzer. Digests of the plant material were also conducted and analyzed using colorimetry, inductively coupled plasma or atomic absorption spectroscopy to determine concentrations of other elements including phosphorus, potassium and metals.

Results and Discussion

PART A: Soil Nutrients and Crop Growth Responses At the Four Field Research Sites in 2003 and 2004

2003 Field Data

TABLE A.1.2003.

Concentrations in *Hog Manure* Applied at Dixon Crop Site in Spring 2003 for 2003 Season

Tot. N	NH4	NO3	Tot. P	Avail P	K	Ca	Mg	Cu
Fe	Mn	Zn	B	Na				
----------ug/ml----------								
1216	1087	-	77	2	1113	447	89	1.2
28	3.1	4.5	1.0	510				

Application rates of nutrient in kg/ha

Rate gpa									
3330	40	36	-	2.5	.07	37	14.8	2.9	0.04
	0.9	0.10	0.1	0.03	17				

Concentrations in *Cattle Manure* Applied at Dixon Crop Site in Spring 2003 for 2003 Season

Tot. N	NH4	NO3	Tot. P	Avail P	K	Ca	Mg	Cu
Fe	Mn	Zn	S	Na				

---ug/g wet manure---

5330	498	-	1650	43	3433	9253	3638	17.5	
739	67	33	1360	750					

Application rates of nutrient in kg/ha

Rate T/ha (dry)									
7.6	81	7.6	-	25	0.7	51	141	55	
0.3	11	1.1	0.5	20.7	11.4				

TABLE A.2.2003.

Concentrations in *Hog Manure* Applied at Melfort Crop Site in Fall 2002 for 2003 Season

Tot. N	NH4	NO3	Tot. P	Avail P	K	Ca	Mg	Cu	
Fe	Mn	Zn	B	Na					
---ug/ml---									
3119	2055	-	41	2.3	1053	388	124	0.54	
10	1.23	0.4	1.5	414					

Application rates of nutrient in kg/ha

Rate gpa									
3300	103	68	-	1.4	0.08	35	13	4.1	0.02
0.3	0.04	0.01	0.05	13.7					

TABLE A.3. 2003

Concentrations in *Hog Manure* Applied at Plenty Crop Site in Fall 2002 for 2003 Season

Tot. N	NH4	NO3	Tot. P	Avail P	K	Ca	Mg	Cu
Fe	Mn	Zn	B	Na				
ug/ml								
2758	1476	-	136	9.1	1148	218	61	0.87
25.7	1.39	2.9	-	912				

Application rates of nutrient in kg/ha

Rate gpa									
3300	91	49	-	4.5	0.30	38	7.2	2.0	.03
	0.8	0.04	0.1	-	30				

TABLE A.4.2003.

Concentrations in *Hog Manure* Applied at Irrigated Riverhurst Crop Site in Fall 2002 for 2003 Season

Tot. N	NH4	NO3	Tot. P	Avail P	K	Ca	Mg	Cu
Fe	Mn	Zn	B	Na				
ug/ml								
3354	2025	-	122	9	1320	184	62	1.3
17	1.6	4.0	-	422				

Application rates of nutrient in kg/ha

Rate gpa									
3300	111	67	-	4.0	0.3	44	6.1	2.0	0.04
	0.6	0.05	0.13						

Table A.5.2003. Spring 2003 Soil Data for All Sites

Sites: Dixon Hog, Dixon Cattle, Melfort, Plenty, Riverhurst Irrigated, SK

		Crop Harvest Fall 2003		Spring 2003 Soil Samples																	
		Grain Yld		Straw Yld		pH		Elect Cond		Org Carbon		Total N		Total P		Kelowna K		Kelowna P		NO3 N		NH4 N		SO4 S	
Dixon Hog Manure Site																									
Rate of Manure Application																									
Trt	Rate 2002	Rate 2003	Rate 2002	Rate 2003	2001	2002	2003																		
1	0	0	0	0	0	0	0																		
2	1	1	1	1	1	1	1																		
3	2	2	2	2	2	2	2																		
4	4	4	4	4	4	4	4																		
5	1	1	1	1	1	1	1																		
6	2	2	2	2	2	2	2																		
7	4	4	4	4	4	4	4																		
8	1	1	1	1	1	1	1																		
9	2	2	2	2	2	2	2																		
10	4	4	4	4	4	4	4																		
11	1	1	1	1	1	1	1																		
12	2	2	2	2	2	2	2																		
13	4	4	4	4	4	4	4																		
14	1	1	1	1	1	1	1																		
15	2	2	2	2	2	2	2																		
16	4	4	4	4	4	4	4																		
17	1	1	1	1	1	1	1																		
18	2	2	2	2	2	2	2																		
19	4	4	4	4	4	4	4																		
20	1	1	1	1	1	1	1																		
21	2	2	2	2	2	2	2																		
22	4	4	4	4	4	4	4																		
23	1	1	1	1	1	1	1																		
24	2	2	2	2	2	2	2																		
25	4	4	4	4	4	4	4																		
26	1	1	1	1	1	1	1																		
27	2	2	2	2	2	2	2																		
28	4	4	4	4	4	4	4																		
29	1	1	1	1	1	1	1																		
30	2	2	2	2	2	2	2																		
31	4	4	4	4	4	4	4																		
32	1	1	1	1	1	1	1																		
33	2	2	2	2	2	2	2																		
34	4	4	4	4	4	4	4																		
35	1	1	1	1	1	1	1																		
36	2	2	2	2	2	2	2																		
37	4	4	4	4	4	4	4																		
38	1	1	1	1	1	1	1																		
39	2	2	2	2	2	2	2																		
40	4	4	4	4	4	4	4																		
41	1	1	1	1	1	1	1																		
42	2	2	2	2	2	2	2																		
43	4	4	4	4	4	4	4																		
44	1	1	1	1	1	1	1																		
45	2	2	2	2	2	2	2																		
46	4	4	4	4	4	4	4																		
47	1	1	1	1	1	1	1																		
48	2	2	2	2	2	2	2																		
49	4	4	4	4	4	4	4																		
50	1	1	1	1	1	1	1																		
51	2	2	2	2	2	2	2																		
52	4	4	4	4	4	4	4																		
53	1	1	1	1	1	1	1																		
54	2	2	2	2	2	2	2																		
55	4	4	4	4	4	4	4																		
56	1	1	1	1	1	1	1																		
57	2	2	2	2	2	2	2																		
58	4	4	4	4	4	4	4																		
59	1	1	1	1	1	1	1																		
60	2	2	2	2	2	2	2																		
61	4	4	4	4	4	4	4																		
62	1	1	1	1	1	1	1																		
63	2	2	2	2	2	2	2																		
64	4	4	4	4	4	4	4																		
65	1	1	1	1	1	1	1																		
66	2	2	2	2	2	2	2																		
67	4	4	4	4	4	4	4																		
68	1	1	1	1	1	1	1																		
69	2	2	2	2	2	2	2																		
70	4	4	4	4	4	4	4																		
71	1	1	1	1	1	1	1																		
72	2	2	2	2	2	2	2																		
73	4	4	4	4	4	4	4																		
74	1	1	1	1	1	1	1																		
75	2	2	2	2	2	2	2																		
76	4	4	4	4	4	4	4																		
77	1	1	1	1	1	1	1																		
78	2	2	2	2	2	2	2																		
79	4	4	4	4	4	4	4																		
80	1	1	1	1	1	1	1																		
81	2	2	2	2	2	2	2																		
82	4	4	4	4	4	4	4																		
83	1	1	1	1	1	1	1																		
84	2	2	2	2	2	2	2																		
85	4	4	4	4	4	4	4																		
86	1	1	1	1	1	1	1																		
87	2	2	2	2	2	2	2																		
88	4	4	4	4	4	4	4																		
89	1	1	1	1	1	1	1																		
90	2	2	2	2	2	2	2																		
91	4	4	4	4	4	4	4																		
92	1	1	1	1	1	1	1																		
93	2	2	2	2	2	2	2																		
94	4	4	4	4	4	4	4																		
95	1	1	1	1	1	1	1																		
96	2	2	2	2	2	2	2																		
97	4	4	4	4	4	4	4																		
98	1	1	1	1	1	1	1																		
99	2	2	2	2	2	2	2																		
100	4	4	4	4	4	4	4																		
101	1	1	1	1	1	1	1																		
102	2	2	2	2	2	2	2																		
103	4	4	4	4	4	4	4																		
104	1	1	1	1	1	1	1																		
105	2	2	2	2	2	2	2																		
106	4	4	4	4	4	4	4																		
107	1	1	1	1	1	1	1																		
108	2	2	2	2	2	2	2																		
109	4	4	4	4	4	4	4																		
110	1	1	1	1	1	1	1																		
111	2	2	2	2	2	2	2																		
112	4	4	4	4	4	4	4																		
113	1	1	1	1	1	1	1																		
114	2	2	2	2	2	2	2																		
115	4	4	4	4	4	4	4																		
116	1	1	1	1	1	1	1																		
117	2	2	2	2	2	2	2																		
118	4	4	4	4	4	4	4																		
119	1	1	1	1	1	1	1																		
120	2	2	2	2	2	2	2																		
121	4	4	4	4	4	4	4																		
122	1	1	1	1	1	1	1																		
123	2	2	2	2	2	2	2																		
124	4	4	4	4	4	4	4																		
125	1	1	1	1	1	1	1																		
126	2	2	2	2	2	2	2																		
127	4	4	4	4	4	4	4																		
128	1	1	1	1	1	1	1																		
129	2	2	2	2	2	2	2																		
130	4	4	4	4	4	4	4																		
131	1	1	1	1	1	1	1																		
132	2	2	2	2	2	2	2																		
133	4	4	4	4	4	4	4																		
134	1	1	1	1	1	1	1																		
135	2	2	2	2	2	2	2																		
136	4	4	4	4	4	4	4																		
137	1	1	1	1	1	1	1																		
138	2	2	2	2	2	2	2																		
139	4	4	4	4	4	4	4																		
140	1	1	1	1	1	1	1																		
141	2	2	2	2	2	2	2																		
142	4	4	4	4	4	4	4																		
143	1	1	1	1	1	1	1																		
144	2	2	2	2	2	2	2																		
145	4	4	4	4	4	4	4																		
146	1	1	1	1	1	1	1																		
147	2	2	2	2	2	2	2																		
148	4	4	4	4	4	4	4																		
149	1	1	1	1	1	1	1																		
150	2	2	2	2	2	2	2																		
151	4	4	4	4	4	4	4																		
152	1	1	1	1	1	1	1																		
153	2	2	2	2	2	2	2																		
154	4	4	4	4	4	4	4																		
155	1	1	1	1	1	1	1																		
156	2	2	2	2	2	2	2																		
157	4	4	4	4	4	4	4																		
158	1	1	1	1	1	1	1																		
159	2	2	2	2	2	2	2																		
160	4	4	4	4	4	4	4																		
161	1	1	1	1	1	1	1																		
162	2	2	2	2	2	2	2																		
163	4	4	4	4	4	4	4																		
164	1	1	1	1	1	1	1																		
165	2	2	2	2	2	2	2																		
166	4	4	4	4	4	4	4																		
167	1	1	1	1	1	1	1																		
168	2	2	2	2	2	2	2																		
169	4	4	4	4	4	4	4																		
170	1	1	1	1	1	1	1																		
171	2	2	2	2	2	2	2																		
172	4	4	4	4	4	4	4																		
173	1	1	1	1	1	1	1																		
174	2	2	2	2	2	2	2																		
175	4	4	4	4	4	4	4																		
176	1	1	1	1	1	1	1																		
177	2	2	2	2	2	2	2																		
178	4	4	4	4	4	4	4																		
179	1	1	1	1	1	1	1																		
180	2	2	2	2	2	2	2																		
181	4	4	4	4	4	4	4																		
182	1	1	1	1	1	1	1																		
183	2	2	2	2	2	2	2																		
184	4	4	4	4	4	4	4																		
185	1	1	1	1	1	1	1																		
186	2	2	2	2	2	2	2																		
187	4	4	4	4	4	4	4																		
188	1	1	1	1	1	1	1																		
189	2	2	2	2	2	2	2																		
190	4	4	4	4	4	4	4																		
191	1	1	1	1	1	1	1																		
192	2	2	2	2	2	2	2																		
193	4	4	4	4	4	4	4																		
194	1	1	1	1	1	1	1																		
195	2	2	2	2	2	2	2																		
196	4	4	4	4	4	4	4																		
197	1	1	1	1	1	1	1																		
198	2	2	2	2	2	2	2																		
199	4	4	4	4	4	4	4																		
200	1	1	1	1	1	1	1																		
201	2	2	2	2	2	2	2																		
202	4	4	4	4	4	4	4																		
203	1	1	1	1	1	1	1																		
204	2	2	2	2	2	2	2																		
205	4	4	4	4	4	4	4																		
206	1	1	1	1	1	1	1																		
207	2	2	2	2	2	2	2																		
208	4	4	4	4	4	4	4																		
209	1	1	1	1	1	1	1																		
210	2	2	2	2	2	2	2																		
211	4	4	4	4	4	4	4																		
212	1	1	1	1	1	1	1																		
213	2	2	2	2	2	2	2																		
214	4	4	4	4	4	4	4																		
215	1	1	1	1	1	1	1																		
216	2	2	2	2	2	2	2																		
217	4	4	4	4	4	4	4																		
218	1	1	1	1	1	1	1																		
219	2	2	2	2	2	2	2																		
220	4	4	4	4	4	4	4																		
221	1	1	1	1	1	1	1																		
222	2	2	2	2	2	2	2																		
223	4	4	4	4	4	4	4																		
224	1	1	1	1	1	1	1																		
225	2	2	2	2	2	2	2																		
226	4	4	4	4	4	4	4																		
227	1	1	1	1	1	1	1																		
228	2	2	2	2	2	2	2																		
229	4	4	4	4	4	4	4																		
230	1	1	1	1	1	1	1																		
231	2	2	2	2	2	2	2																		
232	4	4	4	4	4	4	4																		
233	1	1	1	1	1	1	1																		
234	2	2	2	2	2	2	2																		
235	4	4	4	4	4	4	4																		
236	1	1	1	1	1	1	1																		
237	2	2	2	2	2	2	2																		
238	4	4	4	4	4	4	4																		
239	1	1	1	1	1	1	1																		
240	2	2	2	2	2	2	2																		
241	4	4	4	4	4	4	4																		
242	1	1	1	1	1	1	1																		
243	2	2	2	2	2	2	2																		
244	4	4	4	4	4	4	4																		
245	1	1	1	1	1	1	1																		
246	2	2	2	2	2	2	2																		
247	4	4	4	4	4	4	4																		
248	1	1	1	1	1	1	1																		
249	2	2	2	2	2	2	2																		
250	4	4	4	4	4	4	4																		
251	1	1	1	1	1	1	1																		
252	2	2	2	2	2	2	2																		
253	4	4	4	4	4	4	4																		
254	1	1	1	1	1	1	1																		
255	2	2	2	2	2	2	2																		
256	4	4	4	4	4	4	4																		
257	1	1	1	1	1	1	1																		
258	2	2	2	2	2	2	2																		
259	4	4	4	4	4	4	4																		
260	1	1	1	1	1	1	1																		
261	2	2	2	2	2	2	2																		
262	4	4	4	4	4	4	4																		
263	1	1	1	1	1	1	1																		
264	2	2	2	2	2	2	2																		
265	4	4	4	4	4	4	4																		
266	1	1	1	1	1	1	1																		
267	2	2	2	2	2	2	2																		
268	4	4	4	4	4	4	4																		
269	1	1	1	1	1	1	1																		
270	2	2	2	2	2	2	2																		
271	4	4	4	4	4	4	4																		
272	1	1	1	1	1	1	1																		
273	2	2	2	2	2	2	2																		
274	4	4	4	4	4	4	4																		
275	1	1	1	1	1	1	1																		
276	2	2	2	2	2	2	2																		
277	4	4	4	4	4	4	4																		
278	1	1	1	1	1	1	1																		
279	2	2	2	2	2	2	2																		
280	4	4	4	4	4	4	4																		
281	1	1	1	1	1	1	1																		
282	2	2	2	2	2	2	2																		
283	4	4	4	4	4	4	4																		
284	1	1	1	1	1	1	1																		
285	2	2	2	2	2	2	2																		
286	4	4	4	4	4	4	4																		
287	1	1	1	1	1	1	1																		
288	2	2	2	2	2	2	2																		
289	4	4	4	4	4	4	4																		
290	1	1	1	1	1	1	1																		
291	2	2	2	2	2	2	2																		
292	4	4	4	4	4	4	4																		
293	1	1	1	1	1	1	1																		
294	2	2	2	2	2	2	2																		
295	4	4	4	4	4	4	4																		
296	1	1	1	1	1	1	1																		
297	2	2	2	2	2	2	2																		
298	4	4	4	4	4	4	4																		
299	1	1	1	1	1	1	1																		
300

Table A.6.2003. Dixon 2003 Barley Yield in Swine Manure Plots

2003 Barley Crop Harvest — Regular Hog Plots-No Phosphorus Added

Rate of Manure Application-One Time

Trt	Rate 1997	1998	1999	2000	2001	2002	2003	N	Crop Harvest Fall 2003 Grain Yld		Straw Yld	
2	0	0	0	0	0	0	0	4	1570	425	915	270
3	1	0	0	1	0	0	1	4	3528	803	2850	616
5	2	0	0	2	0	0	2	4	3538	432	3878	970
8	4	0	0	4	0	0	4	4	3220	877	3323	769

Rate of Manure Application-Annual

Trt	Rate 1997	1998	1999	2000	2001	2002	2003	N				
2	0	0	0	0	0	0	0	4	1570	425	915	270
4	1	1	1	1	1	1	1	4	3708	492	3550	505
7	2	2	2	2	2	2	2	4	3805	880	4005	826
9	4	4	4	4	4	4	4	4	3375	1272	3396	1266

Rate of Manure Application-Annual & Skipped

Trt	Rate 1997	1998	1999	2000	2001	2002	2003	N				
2	0	0	0	0	0	0	0	4	1570	425	915	270
3	1	0	0	1	0	0	1	4	3528	803	2850	616
4	1	1	1	1	1	1	1	4	3708	492	3550	505
5	2	0	0	2	0	0	2	4	3538	432	3878	970
7	2	2	2	2	2	2	2	4	3805	880	4005	826
8	4	0	0	4	0	0	4	4	3220	877	3323	769
9	4	4	4	4	4	4	4	4	3375	1272	3396	1266

Method of Manure Application-Annual

Trt	Method	N	Grain Yld		Straw Yld	
1	Control-Average		1578	518	1178	397
2	Control-Disturbed	4	1570	425	915	270
4	1X1X1X1X1X1X1X Injection @12"	4	3708	492	3550	505
10	1X1X1X1X1X1X1X Injection @ 24"	4	3970	856	3623	556
11	H2O	4	2858	1054	2180	827
12	1X1X1X 1X1X1X1XBroadcast & Incorporated	4	3180	485	2638	547

Source and Rate of Annual N Application-Balanced

Trt		Rate 1997	1998	1999	2000	2001	2002	2003	N				
2	Hog	0	0	0	0	0	0	0	4	1570	425	915	270
4	Hog	1	1	1	1	1	1	1	4	3708	492	3550	505
7	Hog	2	2	2	2	2	2	2	4	3805	880	4005	826
9	Hog	4	4	4	4	4	4	4	4	3375	1272	3396	1266
1	Hog	0	0	0	0	0	0	0	4	1578	518	1178	397
13	Urea	1	1	1	1	1	1	1	4	2768	306	2275	402
14	Urea	2	2	2	2	2	2	2	4	3000	514	2617	442
15	Urea	4	4	4	4	4	4	4	4	2850	575	2617	310

Alternating Hog Manure Application

Trt	Rate 1997	1998	1999	2000	2001	2002	2003	N				
1	0	0	0	0	0	0	0	4	1578	518	1178	397
2	0	0	0	0	0	0	0	4	1570	425	915	270
5	2	0	0	2	0	0	2	4	3538	432	3878	970
6	2	0	2	2	0	2	2	4	3700	1085	2665	780
7	2	2	2	2	2	2	2	4	3805	880	4005	826

LSD (0.05) 507 784

Note 1. Crop harvest (grain and straw) means in kg/ha

2. Means in the first column are followed by Std.deviations in the second column

3. N=number of observations

Table A.6.2003. Dixon 2003 Barley Yield in Swine Plots cont'd

2003 Barley Crop Harvest

Combined Plots: Hog No Phos Plots and Hog + Phosphorus Plots

Rate of Manure Application-One Time

Tr	Rate 1997	1998	1999	2000	2001	2002	2003	N	Crop Harvest Fall 2003 Grain Yld. No Phos		Grain Yld. + Phos		Crop Harvest Fall 2003 Straw Yld. No Phos		Straw Yld. + Phos	
2	0	0	0	0	0	0	0	4	1570	425	1155	579	915	270	870	298
4	1	1	1	1	1	1	1	4	3528	603	3163	742	2850	518	3568	857
1	2	2	2	2	2	2	2	4	3538	432	2903	1099	3878	970	3518	1355
5	2	0	2	2	0	0	2	4	3220	877	3080	510	3323	769	4295	918
9	4	4	4	4	4	4	4	4								

Rate of Manure Application-Annual

Tr	Rate 1997	1998	1999	2000	2001	2002	2003	N								
2	0	0	0	0	0	0	0	4	1570	425	1155	579	915	270	870	298
4	1	1	1	1	1	1	1	4	3708	492	3638	1502	3550	505	3868	1620
1	2	2	2	2	2	2	2	4	3805	880	2810	1136	4005	826	3588	1153
9	4	4	4	4	4	4	4	4	3375	1272	3030	1217	3398	1268	3935	1497

Rate of Manure Application-Annual & Skipped

Tr	Rate 1997	1998	1999	2000	2001	2002	2003	N								
2	0	0	0	0	0	0	0	4	1570	425	1155	579	915	270	870	298
3	1	0	1	0	1	0	1	4	3526	603	3163	742	2850	518	3568	857
4	1	1	1	1	1	1	1	4	3708	492	3638	1502	3550	505	3868	1620
5	2	0	2	2	0	0	2	4	3538	432	2903	1099	3878	970	3518	1355
7	2	2	2	2	2	2	2	4	3805	880	2810	1136	4005	826	3588	1153
8	4	0	0	4	0	0	4	4	3220	877	3080	510	3323	769	4295	918
9	4	4	4	4	4	4	4	4	3375	1272	3030	1217	3398	1268	3935	1497

Method of Manure Application-Annual

Tr	Method	N	Grain Yld No Phos		Grain Yld. + Phos		Straw Yld No Phos		Straw Yld. + Phos	
1	Control-Averags	4	1578	518	1273	573	1178	397	1165	509
2	Control-Disturbed	4	1570	425	1155	579	915	270	870	298
4	1X1X1X1X1X1X1X Injection @12"	4	3708	492	3638	1502	3550	505	3868	1620
10	1X1X1X1X1X1X1X Injection @ 24	4	3910	856	3028	624	3523	556	3330	495
11	1X1X1X1X1X1X1X WATER ONLY IN 2003	4	2956	1054	2158	827	2180	827	2140	1076
12	1X1X1X 1X1X1X1XBroadcast & Incorporated	4	3183	485	3168	1302	2635	547	3283	1600

Source and Rate of Annual N Application-Balanced

Tr		Rate 1997	1998	1999	2000	2001	2002	2003	N								
2	Hog	0	0	0	0	0	0	0	4	1570	425	1155	579	915	270	870	298
4	Hog	1	1	1	1	1	1	1	4	3708	492	3638	1502	3550	505	3868	1620
1	Hog	2	2	2	2	2	2	2	4	3805	880	2810	1136	4005	826	3588	1153
9	Hog	4	4	4	4	4	4	4	4	3375	1272	3030	1217	3398	1268	3935	1497
1	Hog	0	0	0	0	0	0	0	4	1578	518	1273	573	1178	397	1165	509
13	Urea	1	1	1	1	1	1	1	4	2768	306	2575	834	2275	402	2372	614
14	Urea	2	2	2	2	2	2	2	4	3000	514	3160	1842	2617	442	3248	1915
15	Urea	4	4	4	4	4	4	4	4	2650	579	2498	850	2617	310	2838	1100

Alternating Hog Manure Application

Tr	Rate 1997	1998	1999	2000	2001	2002	2003	N								
1									1578	518	1273	573	1178	397	1165	509
2	0	0	0	0	0	0	0	4	1570	425	1155	579	915	270	870	298
3	0	0	1	1	0	0	1	4	3538	432	2903	1099	3878	970	3518	1355
5	2	0	2	2	0	0	2	4	3700	1088	3143	1274	2660	780	3148	1354
7	2	2	2	2	2	2	2	4	3805	880	2810	1136	4005	826	3588	1153

Note 1. Crop harvest (grain and straw) means in kg/ha

2 Means in the first column are followed by Std deviations in the second column

3. N=Number of observations

4. Phosphorus (Ammonium Phosphate) was added in Spring 2001 and Spring 2002 at a rate of 30 kg/ha

Table A.7. 2003. Dixon 2003 Barley Yield in Cattle Manure Plots

2003 Barley Crop Harvest

Rate of Manure Application-One Time

Trt	Rate 1997	1998	1999	2000	2001	2002	2003	N	Crop Harvest Fall 2003 Grain Yld.		Straw Yld.	
1	0	0	0	0	0	0	0	4	1658	204	1343	224
2	1	0	0	1	0	0	1	4	2348	396	2702	1374
4	2	0	0	2	0	0	2	4	3368	254	2870	74
7	4	0	0	4	0	0	4	4	3238	1339	3023	1255

Rate of Manure Application-Annual

Trt	Rate 1997	1998	1999	2000	2001	2002	2003	N				
1	0	0	0	0	0	0	0	4	1658	204	1343	224
3	1	1	1	1	1	1	1	4	2758	272	2528	286
6	2	2	2	2	2	2	2	4	3680	616	3650	1255
8	4	4	4	4	4	4	4	4	4043	907	4278	356

Rate of Manure Application-Annual & Skipped

Trt	Rate 1997	1998	1999	2000	2001	2002	2003	N				
1	0	0	0	0	0	0	0	4	1658	204	1343	224
2	1	0	0	1	0	0	1	4	2348	396	2702	1374
3	1	1	1	1	1	1	1	4	2758	272	2528	286
4	2	0	0	2	0	0	2	4	3368	254	2870	74
6	2	2	2	2	2	2	2	4	3680	616	3650	1255
7	4	0	0	4	0	0	4	4	3238	1339	3023	1255
8	4	4	4	4	4	4	4	4	4043	907	4278	356

Incorporation Timing - Annual

Trt	Method	N				
1	0X0X0X0X0X0X0X Control with incorp	4	1658	204	1343	224
3	1X1X1X 1X1X1X1XBroadcast & incorporated	4	2758	272	2528	286
5	1X1X1X 1X1X1X1XBroadcast/Delayed Incorp	4	2693	465	2410	678

Source and Rate of Annual N Application-Balanced

Trt		Rate 1997	1998	1999	2000	2001	2002	2003	N				
1	Cntr	0	0	0	0	0	0	0	4	1658	204	1343	224
3	Cattle	1	1	1	1	1	1	1	4	2758	272	2528	286
6	Cattle	2	2	2	2	2	2	2	4	3680	616	3650	1255
8	Cattle	4	4	4	4	4	4	4	4	4043	907	4278	356
10	Urea	1	1	1	1	1	1	1	4	3335	985	3385	731
11	Urea	2	2	2	2	2	2	2	4	3063	786	3455	576
12	Urea	4	4	4	4	4	4	4	4	2715	769	3155	1023

Alternating Cattle Manure Application

Trt	Rate 1997	1998	1999	2000	2001	2002	2003	N				
1	0	0	0	0	0	0	0	4	1658	204	1343	224
4	2	0	0	2	0	0	2	4	3368	254	2870	74
5	2	0	2	2	0	2	0	4	2860	540	2310	793
6	2	2	2	2	2	2	2	4	3680	616	3650	1255
								LSD 0.05	790		907	

Note 1: Crop harvest (grain and straw) means in kg /ha

2 Means in the first column are followed by Std deviations in the second column

3. N=Number of observations

Table A.8. 2003. Melfort 2003 Canola Crop Data

2003 Canola Crop Harvest

Manure Rate Trt	Rate 2000	2001	2002	2003	N	Crop Harvest Fall 2003: Grain Yld	Straw Yld	Crop Sample CNS Analysis: Grain C	Straw C	Grain S	Straw S	Grain N	Straw N
1	0	0	0	0	12	650	1251	61.4	44.1	0.34	0.37	2.84	0.32
2	1	1	1	1	12	1952	3857	60.1	43.3	0.44	0.32	3.54	0.40
3	2	0	2	0	12	1577	3070	60.5	43.7	0.42	0.32	3.34	0.36
4	3	0	0	3	12	2133	3831	59.2	43.0	0.52	0.25	4.41	0.75
5	U	U	U	U	12	1510	3485	49.1	44.2	0.35	0.18	3.21	0.71
					LSD$_{0.05}$	225	399	5.7	0.7	0.05	0.05	0.48	0.11

Sulphur Application		N	Grain Yld	Straw Yld	Grain C	Straw C	Grain S	Straw S	Grain N	Straw N
1	No Sulphur Added	20	1324	2977	53.8	44.2	0.38	0.33	3.19	0.62
2	Elemental S (Tiger 90)	20	1679	3321	59.2	43.8	0.41	0.21	3.54	0.44
3	Potassium Sulfate(K$_2$SO$_4$)	20	1690	3060	60.2	43.0	0.46	0.32	3.67	0.46
		LSD$_{0.05}$	175	309	4.5	0.5	0.04	0.04	0.37	0.09

Rate of Manure X Sulfur Ammendment						N	Grain Yld		Straw Yld		Grain C		Straw C		Grain S		Straw S		Grain N		Straw N	
1	0	0	0	0																		
	1	No S				4	635	236	1315	402	61.4	0.2	45.2	1.0	0.34	0.01	0.43	0.06	2.81	0.10	0.35	0.04
	2	Tiger 90				4	570	246	1225	411	61.4	0.1	43.7	0.9	0.34	0.01	0.33	0.08	2.84	0.07	0.29	0.03
	3	SO$_4$-S				4	745	140	1512	365	61.3	0.4	43.5	1.3	0.35	0.02	0.36	0.02	2.86	0.07	0.30	0.02
2	1	1	1	1																		
	1	No S				4	1783	343	3733	726	60.0	0.2	43.4	0.7	0.43	0.01	0.38	0.20	3.57	0.57	0.43	0.03
	2	Tiger 90				4	2173	355	4206	764	60.3	0.4	43.1	1.1	0.41	0.04	0.22	0.12	3.35	0.13	0.31	0.02
	3	SO$_4$-S				4	1900	479	3635	917	60.1	0.5	43.4	1.1	0.47	0.07	0.35	0.08	3.71	0.47	0.45	0.22
3	2	0	2	0																		
	1	No S				4	1398	360	3025	762	60.2	0.6	44.0	1.0	0.42	0.06	0.35	0.23	3.33	0.27	0.33	0.06
	2	Tiger 90				4	1635	495	3193	746	60.8	0.4	44.1	0.4	0.41	0.05	0.24	0.14	3.32	0.28	0.33	0.04
	3	SO$_4$-S				4	1707	506	2993	881	60.6	0.2	43.0	1.0	0.43	0.03	0.36	0.05	3.39	0.29	0.37	0.03
4	3	0	0	3																		
	1	No S				4	2155	193	4122	222	59.1	0.7	43.8	1.2	0.50	0.02	0.29	0.13	4.28	0.25	0.73	0.18
	2	Tiger 90				4	2175	160	3892	405	59.1	0.2	43.2	0.8	0.50	0.04	0.17	0.08	4.38	0.28	0.76	0.14
	3	SO$_4$-S				4	2058	285	3478	471	59.3	0.2	42.1	0.6	0.56	0.02	0.30	0.05	4.56	0.23	0.77	0.08
5	U	U	U	U																		
	1	No S				4	660	1190	2688	2057	28.1	32.6	44.6	0.9	0.19	0.23	0.19	0.12	1.95	2.28	1.21	0.59
	2	Tiger 90				4	1840	259	4088	385	59.5	1.5	44.7	0.7	0.37	0.06	0.10	0.03	3.80	0.41	0.50	0.28
	3	SO$_4$-S				4	2030	108	3680	346	59.7	0.5	43.3	0.8	0.47	0.04	0.24	0.04	3.87	0.31	0.40	0.06
					LSD$_{0.05}$		470		831		10.0		1.1		0.08		0.09		0.83		0.19	

Note 1. Crop harvest (grain and straw) means in kg ha^{-1}

2. Carbon, nitrogen, and sulfur means in percent (%)

3 Means in the first column are followed by Std deviations in the second column

4. N=Number of observations

Table A.9.2003. Plenty 2003 Spring Wheat Crop Data

2003 Spring Wheat Crop Harvest

Regime	1999	2000	2001	2002	2003	N	Crop Harvest Fall 2003 Grain Yld.	Straw Yld.
1	X	O	O	O	O	15	2577	3122
2	X	O	O	X	O	15	1979	2633
3	X	O	X	O	X	15	1901	2075
4	X	X	O	O	X	15	1913	2391
5	X	X	X	O	O	15	1732	1989
6	X	X	X	X	X	15	1685	2156
						$LSD_{0.10}$	228	240

Source		N	Grain Yld.	Straw Yld.
1	Check	18	2020	2324
2	Low Hog Manure	18	1848	2434
3	High Hog Mnaure	18	2283	2763
4	Low Fertilizer	18	1824	2205
5	High Fertilizer	18	1850	2242
		$LSD_{0.10}$	208	219

Effect of Source within Regime

		N	Grain Yld.		Straw Yld.	
1	X O O O O					
	1 Check	3	2823	421	3247	354
	2 Low Hog Manure	3	2320	424	3047	423
	3 High Hog Mnaure	3	3247	1151	3990	1147
	4 Low Fertilizer	3	1963	437	2350	406
	5 High Fertilizer	3	2533	386	2977	437
2	X O O X O					
	1 Check	3	2042	515	2607	660
	2 Low Hog Manure	3	1980	70	2853	543
	3 High Hog Mnaure	3	2227	902	3020	829
	4 Low Fertilizer	3	1803	472	2353	514
	5 High Fertilizer	3	1840	365	2330	321
3	X O X O X					
	1 Check	3	1890	299	1887	257
	2 Low Hog Manure	3	1627	67	1933	211
	3 High Hog Mnaure	3	2203	261	2380	240
	4 Low Fertilizer	3	1917	449	2100	286
	5 High Fertilizer	3	1870	370	2073	430
4	X X O O X					
	1 Check	3	1883	301	2187	401
	2 Low Hog Manure	3	1957	306	2610	411
	3 High Hog Mnaure	3	2023	437	2543	423
	4 Low Fertilizer	3	1970	261	2410	236
	5 High Fertilizer	3	1733	58	2207	211
5	X X X O O					
	1 Check	3	1780	240	1900	226
	2 Low Hog Manure	3	1503	70	1943	103
	3 High Hog Mnaure	3	2180	98	2407	115
	4 Low Fertilizer	3	1640	402	1917	191
	5 High Fertilizer	3	1573	281	1777	147
6	X X X X X					
	1 Check	3	1733	350	2130	305
	2 Low Hog Manure	3	1687	125	2217	352
	3 High Hog Mnaure	3	1617	341	2233	405
	4 Low Fertilizer	3	1650	126	2133	214
	5 High Fertilizer	3	1567	200	2087	251
		$LSD_{0.10}$	510		537	

Note 1. All means in kg/ha

2 Means in the first column are followed by Std deviations in the second column

3 N=number of observations

Table A.10.2003. Riverhurst 2003 CPS Wheat Crop Data

2003 CPS Wheat Crop Harvest

Regime	1999	2000	2001	2002	2003	N	Crop Harvest Fall 2003 Grain Yld.	Straw Yld.
1	X	O	O	O	O	15	1817	2190
2	X	O	O	X	O	15	2031	2149
3	X	O	X	O	X	15	1883	2057
4	X	X	O	O	X	15	1977	2029
5	X	X	X	O	O	15	2191	2658
6	X	X	X	X	X	15	2207	2582
							LSD (0.10) 306	322

Source		N	Grain Yld.	Straw Yld.
1	Check	18		
2	Low Hog Manure	18		
3	High Hog Mnaure	18		
4	Low Fertilizer	18		
5	High Fertilizer	18		
			LSD (0.10)	

Effect of Source within Regime

		N	Grain Yld.		Straw Yld.	
1	X O O O O					
	1 Check	3	1497	323	1827	259
	2 Low Hog Manure	3	1936	260	1940	252
	3 High Hog Mnaure	3	2790	1081	3343	1227
	4 Low Fertilizer	3	1276	576	1633	622
	5 High Fertilizer	3	1953	436	2207	451
2	X O O X O					
	1 Check	3	1517	661	1917	361
	2 Low Hog Manure	3	2246	802	2347	660
	3 High Hog Mnaure	3	2643	516	2983	520
	4 Low Fertilizer	3	1600	335	1687	297
	5 High Fertilizer	3	1847	529	1813	555
3	X O X O X					
	1 Check	3	1323	284	1537	51
	2 Low Hog Manure	3	2540	547	2650	397
	3 High Hog Mnaure	3	3177	309	3260	692
	4 Low Fertilizer	3	1333	211	1470	248
	5 High Fertilizer	3	1043	155	1367	495
4	X X O O X					
	1 Check	3	1553	264	1653	242
	2 Low Hog Manure	3	2403	289	2247	162
	3 High Hog Mnaure	3	3350	655	3530	409
	4 Low Fertilizer	3	1190	497	1373	316
	5 High Fertilizer	3	1247	172	1343	211
5	X X X O O					
	1 Check	3	1337	556	1647	465
	2 Low Hog Manure	3	3087	381	3410	426
	3 High Hog Mnaure	3	3447	545	4320	584
	4 Low Fertilizer	3	1973	549	2010	392
	5 High Fertilizer	3	1413	166	1903	397
6	X X X X X					
	1 Check	3	1803	370	1867	300
	2 Low Hog Manure	3	2736	145	3220	547
	3 High Hog Mnaure	3	2957	239	3087	521
	4 Low Fertilizer	3	1940	306	2270	480
	5 High Fertilizer	3	1697	714	1857	479
			LSD (0.10)	683		720

Note 1. All means in kg/ha

2. Means in the first column are followed by std deviations in the second column

3. N=Number of observations

Table A.11.2003. Crop Nutrient Concentrations in 2003: All Sites

Sites: Dixon Hog, Dixon Cattle, Melfort, Plenty, Riverhurst Irrigated, SK.

Dixon Hog Manure Site

Rate of Manure Application

Trt	Rate 1995	1996	1997	2000	2001	2002	2003	N
1	0	0	0	0	0	0	0	4
2	1	1	1	1	1	1	1	4
3	2	2	2	2	2	2	2	4
4	4	4	4	4	4	4	4	4
12	1 BAI	1 BAI	1 BAI	1 BAI	1 BAI	1 BAI	1 BAI	4
14	U2	U2	U2	U2	U2	U2	U2	4

Trt	Grain Total N (avg g kg⁻¹)		Grain Total P (avg g kg⁻¹)		Straw Total N (avg g kg⁻¹)		Straw Total P (avg g kg⁻¹)	
1	9478	851	3043	432	3444	230	879	261
2	15566	4106	2555	316	5211	1565	412	169
3	20742	1879	2661	267	5744	1350	369	250
4	22664	2433	3306	538	8764	1969	615	249
12	11790	1788	2805	460	4350	1288	511	332
14	18197	2504	3101	561	5866	937	261	128
LSD 0.05	2097		261		1514		224	

Dixon Hog + Phos Manure Site

Rate of Manure Application

Trt	Rate 1997	1998	1999	2000	2001	2002	2003	N
1	0	0	0	0	0	0	0	4
2	1	1	1	1	1	1	1	4
3	2	2	2	2	2	2	2	4
4	4	4	4	4	4	4	4	4
12	1 BAI	1 BAI	1 BAI	1 BAI	1 BAI	1 BAI	1 BAI	4
14	U2	U2	U2	U2	U2	U2	U2	4

Trt	Grain Total N (avg g kg⁻¹)		Grain Total P (avg g kg⁻¹)		Straw Total N (avg g kg⁻¹)		Straw Total P (avg g kg⁻¹)	
1	19051	82	3104	428	3364	91	879	129
2	16842	3896	2475	426	4821	1371	291	69
3	22358	833	2991	83	6587	1965	560	180
4	22740	1727	3491	264	11021	578	840	261
12	15584	2023	2892	277	4229	258	334	76
14	18586	976	2121	172	5042	564	155	39
LSD 0.05	2291		361		1273		180	

Dixon Cattle Manure Site

Rate of Manure Application

Trt	Rate 1997	1998	1999	2000	2001	2002	2003	N
1	0	0	0	0	0	0	0	4
5	1	1	1	1	1	1	1	4
6	2	2	2	2	2	2	2	4
8	4	4	4	4	4	4	4	4
11	U2	U2	U2	U2	U2	U2	U2	4

Trt	Grain Total N (avg g kg⁻¹)		Grain Total P (avg g kg⁻¹)		Straw Total N (avg g kg⁻¹)		Straw Total P (avg g kg⁻¹)	
1	10179	1045	3503	189	3165	450	726	205
5	12394	1918	3614	178	3412	712	672	185
6	14841	3483	3900	551	4454	1597	1015	506
8	19653	2914	4137	226	6471	3264	1872	724
11	20911	2686	3130	434	6964	1274	505	128
LSD 0.05	2377		406		2121		516	

Plenty Hog Manure Site

Rate of Manure Application

Regime 6

Trt	Rate 1999	2000	2001	2002	2003	N
1	0	0	0	0	0	3
2	1	1	1	1	1	3
3	2	2	2	2	2	3
4	U1	U1	U1	U1	U1	3
5	U2	U2	U2	U2	U2	3

Trt	Grain Total N (avg g kg⁻¹)		Straw Total N (avg g kg⁻¹)	
1	20071	384	2001	561
2	28371	872	4361	847
3	25667	1463	4454	552
4	23569	1190	2452	681
5	25332	2573	2915	187
LSD 0.05	1535		781	

Riverhurst Irrigated Hog Manure Site

Rate of Manure Application

Regime 6

Trt	Rate 1999	2000	2001	2002	2003	N
1	0	0	0	0	0	3
2	1	1	1	1	1	3
3	2	2	2	2	2	3
4	U1	U1	U1	U1	U1	3
5	U2	U2	U2	U2	U2	3

Trt	Grain Total N (avg g kg⁻¹)		Straw Total N (avg g kg⁻¹)	
1	17386	2077	7854	1670
2	20482	4314	4871	2313
3	24356	122	8345	1715
4	19203	641	2991	111
5	21722	824	3229	330
LSD 0.05	4317		2264	

Melfort Hog Manure Site

Rate of Manure Application

Trt	Rate 2000	2001	2002	2003	N
1	0	20	0	0	4
2	1	1	1	1	4
3	2	6	2	2	4
4	4	4	4	4	4
5	U2	U2	U2	U2	4

Trt	Grain Total N (avg g kg⁻¹)		Grain Total S (avg g kg⁻¹)		Straw Total N (avg g kg⁻¹)		Straw Total S (avg g kg⁻¹)	
1	2.81	0.10	0.34	0.01	0.25	0.04	0.43	0.06
2	3.57	0.07	0.42	0.01	0.43	0.03	0.35	0.03
3	3.33	0.27	0.42	0.05	0.39	0.05	0.35	0.03
4	4.26	0.25	0.50	0.03	0.73	0.18	0.22	0.13
5	1.85	2.25	0.15	0.23	1.21	0.59	0.19	0.12
LSD 0.05	1.31		0.11		0.33		0.10	

Melfort Hog + Elemental S Manure Site

Rate of Manure Application

Trt	Rate 2000	2001	2002	2003	N
1	0	20	0	0	4
2	1	1	1	1	4
3	2	6	2	2	4
4	4	4	4	4	4
5	U2	U2	U2	U2	4

Trt	Grain Total N (avg g kg⁻¹)		Grain Total S (avg g kg⁻¹)		Straw Total N (avg g kg⁻¹)		Straw Total S (avg g kg⁻¹)	
1	2.84	0.07	0.34	0.01	0.24	0.03	0.31	0.04
2	3.75	0.12	0.41	0.04	0.31	0.02	0.22	0.12
3	3.32	0.26	0.41	0.04	0.31	0.04	0.24	0.14
4	4.19	0.25	0.50	0.04	0.71	0.14	0.17	0.04
5	1.80	0.41	0.11	0.01	0.30	0.21	0.10	0.03
LSD 0.05	0.31		0.04		0.10		0.07	

Melfort Hog + K_2SO_4 Manure Site

Rate of Manure Application

Trt	Rate 2000	2001	2002	2003	N
1	0	20	0	0	4
2	1	1	1	1	4
3	2	6	2	2	4
4	4	4	4	4	4
5	U2	U2	U2	U2	4

Trt	Grain Total N (avg g kg⁻¹)		Grain Total S (avg g kg⁻¹)		Straw Total N (avg g kg⁻¹)		Straw Total S (avg g kg⁻¹)	
1	2.81	0.07	0.31	0.02	0.32	0.02	0.36	0.02
2	3.71	0.47	0.41	0.07	0.41	0.21	0.30	0.04
3	3.23	0.20	0.43	0.03	0.31	0.5	0.26	0.01
4	4.50	0.23	0.56	0.01	0.77	0.08	0.21	0.03
5	1.87	0.31	0.17	0.04	0.41	0.30	0.24	0.04
LSD 0.05	0.34		0.03		0.11		0.05	

Note: 1) Means in the first column that followed by the same letter in the second column are not significantly different at the 5% level of probability.

2) Least significant difference (at 5%).

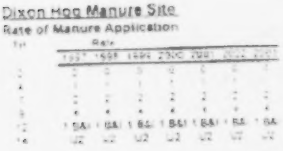
Table A.12.2003. Fall 2003 Soil Residual Nitrate and Ammonium:All Sites

Sites: Dixon Hog, Dixon Cattle, Melfort, Plenty, Riverhurst Irrigated, SK

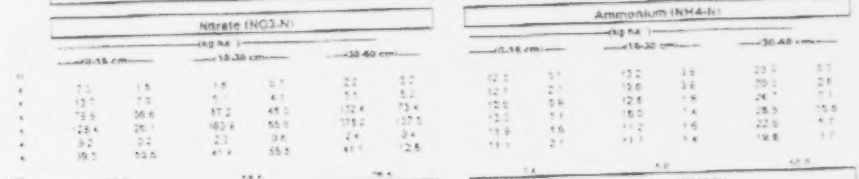
Soil Samples Fall 2003

Dixon Hog Manure Site

Rate of Manure Application

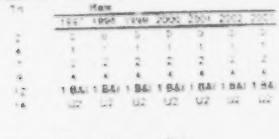


Nitrate (NO3-N) — Ammonium (NH4-N)

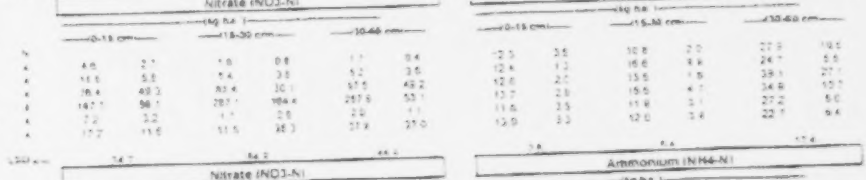


Dixon Hog + Phos Manure Site

Rate of Manure Application



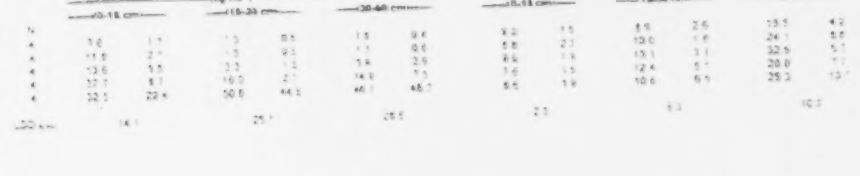
Nitrate (NO3-N) — Ammonium (NH4-N)

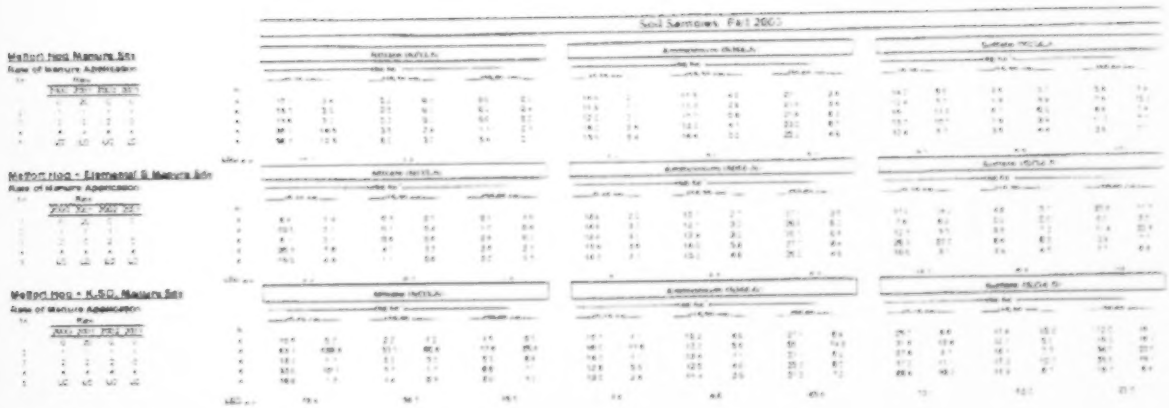


Dixon Cattle Manure Site

Rate of Manure Application

Nitrate (NO3-N) — Ammonium (NH4-N)




Soil Sampling Fall 2007
Wellpot Hog Manure Silt
Rate of Manure Application
Wellpot Hog + Elephant Ø Manure Silt
Rate of Manure Application
Wellpot Hog + K-SD Manure Silt
Rate of Manure Application

2003

2003 Dixon SWINE MANURE Plots Barley

Spring 0-15cm depth Soil Characteristics Before Spring Manure Application

- The soil pH at this site was significantly lowered by repeated manure application: control 7.5 to 4X 7.2. The urea application also decreased the pH. The decrease in pH may explain some of the enhanced uptake of cadmium observed in the crop as reported on in Part B.
- Electrical conductivity (EC) not significantly affected by treatment. All treatments very similar and low ~ .22 mS/cm. Not surprising since it has been over a year since manure was added.
- The organic carbon (O.C.) concentrations were slightly but not significantly increased by the manure and fertilizer treatments, probably related to fertilizing effect of manure increasing biomass production and residue C returns.
- The total N concentrations followed pattern similar to O.C. Treatments with manure or urea had higher total N. The 1x (agronomic rate) treatment had the highest total N and total C and was the only treatment significantly higher than the control. Therefore the agronomic optimal treatment has also resulted in greatest apparent C and N sequestration. The Broadcast and Incorporate has O.C. and total N that is much lower than 1x injected, likely reflecting lower nutrient recovery with broadcast and incorporate (Schoenau et al., 2004).
- Treatments had very little influence on total P. This agrees with only small amounts of P added in swine manure, especially in recent years, and also findings of Qian and Schoenau 2004. Also little or no difference in Kelowna extractable P among treatments. Not surprisingly, Kelowna P is lowest in urea, as the urea treatment has not had any P added in 7 years.
- Nitrate-N was significantly higher in manure and urea treatments than control, as expected. Nitrates increase with rate history from 1X to 2X to 4X. Note that broadcast and incorporated (B&I) significantly lower than 1X injected. The B&I is less efficient. There was not much difference in ammonium as ammonium has likely nitrified to nitrate or been taken up by plants.
- For sulfate, there was lots of variability as one would expect, also the measurement method (turbidometric on autoanalyzer) is not highly precise. No significant differences among treatments, but sampling to depth in previous years has shown lots of sulfate at Dixon, so S deficiency is not an issue at this site.
- Manure addition significantly increased Kelowna extractable K, with a linear relationship with rate. The lowest Kelowna extractable was with urea only, as no K additions are made to this treatment.

Dixon Swine Manure Barley Yields

- There was no significant grain or straw yield response evident from MAP banded at 30 kg P2O5/ha in any of the treatments. This agrees with 2002 findings with flax. Perhaps placing P in band rather than seed placing and/or else the dry conditions early in the spring restricted response to P fertilization. There may be more consistent evidence of a P response in straw yield rather than grain yield, as a trend towards higher straw yield with P fertilizer was sometimes evident.
- Swine manure application significantly increased grain yield over the control, from ~ 1500 kg/ha in control to ~ 3500+ kg/ha in 1X. Note that going from 1X to 2X to 4X did not result in significant grain or straw yield increases. In fact going from 2X to 4X resulted in yield decrease. Toxicity is apparent from the negative effect on yield in 4X compared to 1X and 2X. Same low yield from 4-0-0-4 sequence as 4-4-4-4 sequence, so no cumulative effect. The toxicity effect seems to be mainly related to the impact of high rate applied in that year. Also it is important to remember that manure was spring applied, so the potential salt effect and ammonium toxicity to the crop would be aggravated compared to manure application made the previous fall.
- Broadcast and Incorporated had significantly lower yield than Injected. This is consistent with observations made the past six years in this trial.
- It is interesting that treatment 11, which was 1X manure rate for six years and switched this year to water only at 3300 gpa produced yield significantly higher than the disturbed check: (2800 kg/ha vs. 1500 kg/ha). Water added was only equal to about one quarter inch but may have had some benefit in a dry spring like this. However, a more likely explanation is some residual fertility benefit, as nitrate in 1X treatment in spring 2003 before manure application was significantly higher than the control, also higher in K which is important for barley.
- The 24" versus 12" injection row spacing had no significant influence this year and the yields were very similar.
- Also interesting is comparing the 2-0-0-2 to 2-0-2-2 application frequency. Overall, it appeared that yield is higher with greater application frequency. Residual nutrients are important and greater frequency of application increases them.

2003 Dixon CATTLE MANURE Plots Barley

Spring 0-15cm depth Soil Characteristics Before Spring Manure Application

- There were no significant effects of cattle manure on pH, but there was a trend towards slightly (.1 to .2 pH units) lower pH in manure and fertilizer treatments. The E.C. was also not significantly affected but a trend towards slightly higher E.C. (0.1 mS/cm higher) in manure treatments was evident.
- The Total N in the soil was significantly increased with increasing annual rate of cattle manure. This is not surprising since the O.C. is increasing as well and

nearly all the increase in total N is attributable to organic N increase. This indicates substantially enhanced N mineralization potential.

- The Kelowna extractable P is higher only in the 4X treatment. The urea only treatment is lower than the control due to crop removal, consistent with previous findings. This follows the trend as observed for total P, as total P is only elevated in the 4X repeated cattle manure treatment. All others are similar.
- The surface soil nitrate (0-15 cm) is elevated over the control in the manure and urea treatments by about 10 to 15 kg / ha and, as expected, nitrate increases with increasing application rate. However, there was no significant impact on ammonium, with very little difference among treatments and control. It is obvious that with repeated annual cattle manure applications, after 7 years we are seeing enhanced mineralization and the production and accumulation of nitrate in surface soil.
- The sulfate, as in swine manure plots, is highly variable. There may be a trend towards higher sulfate in cattle manure treatments compared to control, but urea only is also higher.
- Kelowna extractable K is increased by cattle manure addition, as expected and observed in previous years.

Dixon Cattle Manure Barley Yields

- Repeated (7 yrs) annual additions of cattle manure resulted in significant and large increases in barley grain and straw yield in 2003. A significant rate effect was observed, increasing from 1650 kg/ha in control to 2750 kg/ha 1X to 3680 kg/ha 2X to 4040 kg/ha 4X. The urea yields were significantly lower, indicating that the cattle manure is having a positive impact on factors apart from N that are enhancing growth.
- Also evident is a greater residual effect of yearly application sequence versus once every three years, with significantly higher yields in 2003 1X, 2X and 4X where it was applied every year for the past 7 years versus only once every three years. This effect was worth about 300 to 500 kg/ha of additional barley yield. It appears that a fresh application is worth about 500 kg/ha of barley yield as 2-0-0-2-0-0-2 versus 2-0-2-2-0-2-0 yielded higher with the 2003 application.
- Straw yields followed similar patterns to grain yields.
- As in previous years , no statistically significant difference and very little difference (only about 50kg/ha) in yield between immediate incorporation versus 24 hour delayed incorporation. With this manure of low ammonium content and high straw content, it appears that immediate incorporation is not essential, as ammonia volatilization loss potential is not that high.

2003 Melfort SWINE MANURE Plots with/without Added S Canola

Spring 0-15 cm depth Soil Characteristics After Manure Application the Previous Fall

- At this site there was no significant influence of manure treatment on soil pH and the pH values among treatments were very similar. It is important to remember that this represents only 4 years of application and the rates are not high. Also, E.C. is low with very slight impact of manure addition the previous fall on increasing E.C. ie control E.C. 0.14 mS/cm to 0.23mS/cm in 1X treatment. While the increase is statistically significant, it is not biologically significant.
- The organic carbon in manure treatments is slightly elevated, but it is noteworthy that urea treatment O.C. is lower! At this site, S deficiency greatly limited response to added N in this treatment over the last 4 years. The N instead may have just stimulated microbial activity and decomposition of organic matter, resulting in reduced surface soil O.C., especially considering the low yields and residue inputs to begin with.
- The total soil N followed a trend similar to O.C. as expected, since nearly all total N is organic N. Total N is lower in urea treatment than control, but not statistically significantly lower. There was not as large a difference in N as O.C., since one would expect some excess N to accumulate. Also the urea treatment N rate is only 80 kg N/ha.
- The soil total P was enhanced by annual application at the 1X rate (3300 gpa), but not by 2X every second year, which is interesting since it is the same total amount of manure. Still, the 1X enhancement is not statistically significant (large S.D.). Overall, there was not much impact on total P, also not much impact on Kelowna extractable P. In fact, no significant differences among any treatments were observed in Kelowna P, all very similar and low. Urea has lowest Kelowna P.
- The Kelowna extractable K is significantly increased by manure application, and not affected by urea. This is what would be expected. As well, the 1X every year for four years versus 2X rate every second year (same total amount of manure over four years) produces very similar extractable K values as would be expected.
- As expected, spring nitrate-nitrogen is higher (5 times higher) in 1-1-1-1 than in control due to manure addition. The 2-0-2-0 is also significantly higher despite no manure addition the previous fall. This might be related to greater mineralization in the 2-0-2-0, even though it has only seen two years of manure application (12000 gpa total). Urea increased nitrate from 8.5 to 13.2 kg N/ha in top 15 cm, but not as much as 1X manure. Manure went on in fall, but Urea did not go on until spring at seeding. The ammonium N was slightly but significantly enhanced in manure and urea treatments.
- Sulfate in manure treatments was slightly but not statistically higher than the control. Urea treatment was lower than control. Note that compared to the other three long-term swine manure sites, the soil extractable sulfates at Melfort are about 10 times lower. Sulfur deficiency is a problem at this site and there is response to added S.

Melfort Swine Manure 2003 Canola Harvest

Yield

- Compared to the control, the 1X annual rate 1-1-1-1 tripled canola grain yield from 600 kg/ha to 1780 kg/ha and the same trend was evident for straw yield. The 2-0-2-0 still had double the grain yield over the control, so residual effects are evident, but yield still 400 kg/ha less than 1-1-1-1. The 3-0-0-3 with 9900 gpa for 2003 after nothing for the previous two years yielded the highest at 2200 kg/ha. The urea treatment yielded only 660 kg / ha due to severe S deficiency!
- The effect of adding S fertilizer at 40 kg S/ha in the spring of 2002 prior to growing oats has carried over into 2003. There is a significant residual beneficial effect.
- There was no significant effect of S fertilization on control yield, but for 1-1-1-1, the Tiger 90 elemental had the highest yield 2173 kg/ha versus 1783 kg/ha for no S. Sulfate was 1900 kg/ha.
  For 2-0-2-0, both Tiger 90 elemental and sulfate increased yield by about 400 kg/ha
  For 3-0-0-3, there was no significant effect of sulfur fertilization. The yields were all similar. For very high rates of manure in the year of application, the manure itself must supply enough S. For urea, the S fertilizer applications made two years previous resulted in more than tripling of yield!
- Fertilization with sulfur, either sulfate or elemental at 40 kg S/ha has produced significant residual benefit in year 2. The Tiger 90 elemental works well in this application. There is a need to use S fertilization with swine manure on these kinds of soils as a huge yield benefit was observed.

Grain and Straw N and S Concentrations

- Adding manure significantly increased grain and straw N concentration, with greater rates ie 1-1-1-1 vs 3-0-0-3 producing higher N concentration (3.6 to 4.3%N). Protein benefit. We note that urea without S had both lowest yield and seed N concentration (protein) therefore economically bad!
- Sulfur fertilization tended to increase grain N concentrations slightly in manured treatments and produced a huge increase in grain N concentration and a decrease in straw N concentration in the canola, presumably because the S allowed the normal physiological development an d movement of N to the seed.
- Grain sulfur concentrations tended to significantly increase with manure addition compared to the control, while straw S concentrations tended to decline, suggesting that the added N plus S in manure is enhancing protein production and accumulation in the seed. The exception is the urea treatment which is highly S deficient and with very low grain and straw S concentrations.
- Sulfur fertilization of the manure treatments tended to produce slight increases in grain and straw S concentrations in line with the moderate yield increases they were associated with. With urea treatments, the S fertilization produced a near

doubling of the grain S concentration, from 0.19%S unfertilized to 0.47%S fertilized.

2003 Plenty SWINE MANURE Trials Spring Wheat

Spring 0-15cm Soil Depth Characteristics After Manure Application the Previous Fall

- The soil pH was slightly but significantly affected by 5 annual applications of manure: 8.3 in control and urea fertilized to 8.2 1X and 8.1 2X. Decrease in pH is expected due to protons produced during nitrification of ammonium to nitrate.
- The E.C. was also slightly but significantly increased, from 0.28 to 0.45 and 0.52 in manure treatments, but still not enough to be of concern regarding salinity damage effects. More detailed assessment of salinity effects is found in part B of this report.
- The organic carbon was increased from 1.6% O.C. to 1.8 % O.C. in manure and urea treatments. This may be explained by greater plant C production and biomass residue addition from fertilizing effect. Also a heavy clay soil of low organic matter to begin with such as this soil, has lots of storage capacity for O.C. accumulation. More detail is found in part B of this report.
- Total N was significantly increased by manure application over the control, and the amount increased with increasing rate (1X vs 2X). In part, this may be explained by large accumulations of nitrate in the manured treatments, but also by a build-up of organic N.
- The Total P was also significantly increased by manure application, with manure treatments 1-1-1-1-1 having about 150 to 300 kg / ha more total P than control or urea treatments which were both similar. Rates of P added as manure in early years were high because phytase enzyme was not being used yet. Despite increase in total P, the Kelowna extractable P was very low and similar among treatments and not significantly influenced by manure. This likely reflects the high P sorption capacity and buffering power of this high clay content, calcium rich soil.
- The soil nitrate-N in the 0-15 cm depth was increased by 4 times in the 1X repeated rate compared to the control and a 5 times increase in the 2X repeated rate. Urea was similar to the control because the urea was not applied until after sampling in the spring. There is too much nitrate in the 2X repeated rate (10,000 gp a every year for four years, then 6600 gpa for 2003), even in the 1X repeated (5000 gpa year for four years, then 3300 gpa for 2003) there is 75 to 100 kg nitrate nitrogen in the top 15 cm and there is lots below this depth that we know from deep sampling the previous fall. The ammonium N was not significantly different among treatments.
- As expected and consistent with the other sites, addition of manure at low and high rates for five consecutive years significantly increased the Kelowna extractable K.

- At the Plenty site, manure significantly increased extractable sulfate in the soil, so maybe manure is higher in sulfur at this site, perhaps related to water source. Overall, sulfate in soil at this site with manure is ~ 30 kgS/ha so S deficiency is not expected.

Plenty Swine Manure 2003 Spring Wheat Yields

- The yields on checks (controls) was surprisingly good (~ 2000 kg / ha) but one must remember that it was droughted out the year before (no crop) and poor the year before that, so really it is like summerfallow. This is supported by the fact that there is ~ 20 kg nitrate – N/ha in the 0-15cm depth in the checks, which is a fair bit.
- For regime 6 (annual applications of manure) no significant effect of manure or fertilizer urea on yield, probably because there is abundant residual available nutrient.
- For treatments that did not receive manure for this year or two years or four previous years ie 1-1-1-0-0 or 1-0-0-1-0 or 1-0-0-0-0, there was a response to these treatments compared to the control. Even after four years without manure, the single high rate made at the beginning in 1999 is still showing some residual effects. Not true for low rate once at the beginning of the five years. Even for applications made for 2003, if the application frequency is reduced ie 1-0-1, we observed more response to manure this year compared to every year application. May be some toxicity at high rate every year. Once every second or third year is likely best.
- Urea fertilized only treatments are not producing much of a benefit. Yields are similar to the control so must be something else in manure treatments producing yield benefits apart from N such as P, K etc. It could be water, but not likely since 1-0-0-0-0 and 1-0-0-1-0 and 1-1-1-0-0 also have higher yields. Perhaps also urea fertilized was inefficient since it was surface broadcast every year.

2003 Riverhurst Irrigated SWINE MANURE YIELDS CPS Wheat

Spring 0-15cm Soil Depth Characteristics After Manure Application the Previous Fall

- As at Plenty, manure application for five years at low and high rates resulted in significant pH decrease, from 7.1 in control to 6.8 and 6.6 in 1X and 2X treatments. This is a greater decline than at Plenty and can be explained by lower buffering capacity of this soil (less clay) and greater leaching under irrigation.
- The E.C. was only very slightly increased by manure application the previous fall. Again, no evidence for manure application causing salinization of the surface soil.
- The organic carbon was not significantly affected by manure addition at this site, but yield increases from manure haven't been as huge at this site as others in past either due to crops grown ie beans.
- The total N was significantly increased (by about 200 kg N/ha) in the top 15 cm by manure. Only a small portion of the total N increase is accounted for by an

increase in nitrate, so organic N is definitely building up in these soils from manure application.

- Total P also was significantly increased by manure application, but magnitude of response less than at Plenty, possibly due to greater yields and crop P removal in past two or three years in irrigated system compared to dry Plenty. As observed at all other sites, manure application increased Kelowna extractable K significantly in the surface soil.
- Manure application also increased nitrate significantly over the control and the effect increased with rate. The 2X repeated annual rate had double the nitrate compared to the control. The nitrate in the control is still fairly high so a large yield response to added N was not anticipated. Urea had surface soil nitrate similar to control but it was sampled before urea was applied in the spring. Like other sites, no significant influence of treatment on ammonium.
- As at Plenty, manure application significantly increased sulfate in the 0-15 cm depth. May be related to high sulfate in water used in the barn. Again, given these soil levels, S deficiency is not likely to be a factor.

Riverhurst Swine Manure 2003 Irrigated CPS Wheat Yields

- Quite good yield response of ~ 1000 kg/ha increase in wheat grain yield to manure was observed at this site in 2003. Yields of grain around 3000 to 3400 kg/ha achieved in manure treatments are very good. Little or no response to urea compared to control, as observed at Plenty that may be related to good N availability in control, or something else other than N holding back yield, also perhaps low N availability from fertilizer due to broadcast application.
- As at Plenty, there may be a toxic, adverse effect from high rate of manure every year. The high rate treatments that skipped a year or two of application tended to yield best. Definite residual effect of applications made the first three years and then skipped for the next two: 1-1-1-0-0 and 2-2-2-0-0 as these still had yields nearly triple that of the control!
- Residual effect of single high rate application made five years ago is still evident in yield of 2-0-0-0-0 2790 kg/ha vs 1500 kg/ha in control. This is an effect of a single application that has persisted much longer than anticipated.
- Overall the high rate swine treatments (10000gpa 99-02, 6600 gpa 03) produced the highest CPS wheat yield in all application sequences but least in the every year sequence (every year at this rate is harmful)

2004 Field Data

2004

2004 Dixon SWINE MANURE Plots Canola

Spring 0-15cm Soil Depth Characteristics After Manure Application the Previous Fall

- The 2MKCl extractable amounts and the Plant Root Simulator anion exchange membrane (AEM) supply rates were significantly higher in the treatments that received annual manure applications. Amounts of nitrate in excess of 100 kg/ha found in the 2x (6600 gpa) and 4x (13,200 gpa) repeated annual treatments indicate that these rates are causing excessive accumulation of nitrate, while the agronomic rate of 3300 gpa per year is not.
- While the Kelowna extractable P did not show any significant differences among treatments, the Bicarbonate (Olsen) extractable P significantly increased with swine manure application for both the inorganic and organic fractions. Similarly, water extractable P and supply rate to Plant Root Simulator also increased significantly with increasing application rate. The barley grain and straw grown on this site in 2003 also showed significant increases in P concentration and uptake with increasing rate of added manure (See 2003 Agronomic Data), indicating increased availability. These data suggest that Kelowna extractable P may not be sensitive to the effects of manure on increasing P availability in the soil. Compared to the control and the urea fertilized, the agronomic rate 1x did not produce significant increases in soil available P indices, suggesting that repeated application of manure of this composition (low P content relative to N) will not lead to excessive P loading of the soil when applied at agronomic rates.

Dixon Swine Manure 2004 Canola Yields

- The August 20th frost at this site was heavy, and resulted in little or no grain yield. Therefore the yield reported for this site for 2004 is biomass. Given very good moisture conditions for growth, the biomass yields for this site in 2004 were high. Annual applications of manure up to the 2X (6600 gpa) rate resulted in significant yield increases, with manure application resulting in a 10 fold increase in biomass yield over the control. Beyond 2X annual rate, no significant yield increases were observed. A significant residual effect from a 4X application made two years previous was observed. As in every year of this study, broadcast and incorporated swine manure resulted in significantly lower yield than injected. Larger annual applications do produce significant residual effects into the second year that can be attributed to nutrient carryover, especially nitrogen.
- The application of 30 kg P/ha banded as MAP in the fall of 2003 appeared to result in a yield response in the control, 1X and 2X treatments. The increase was greatest in the 1X and is consistent with the relatively low levels of soil available P in this treatment. The response to added phosphorus was greatest in the urea only treatments with more than 1000 kg/ha biomass yield increase, as would be

expected given the draw down of soil P after eight years of addition of urea only with no P added.

Soil Residual Nitrate

- Very large amounts (excessive) of nitrate were found in the 0-60cm depth of the 2x (6600 gpa) annual manure rate and 4x annual rate (13,200 gpa), with more than 400 kg of nitrate-N per hectare in the 4x. The 4x every third year did not show this. The 1x agronomic rate showed only 10 kg nitrate per hectare in top 60 cm. There was evidence of deep leaching of nitrate below the root zone in the 2x every year and 4x every year treatments, with significant elevations in the 60-90cm, 90-120cm and 120-150cm depths. This is more evidence that annual applications of 6600 gpa and 13,200 gpa are too much and will result in deep migration of nitrate. No evidence of deep migration of nitrate was observed for the 13,200 gpa every three years.

2004 Dixon CATTLE MANURE Plots Canola

Spring 0-15cm Soil Depth Characteristics After Manure Application the Previous Fall

- Spring soil nitrate concentrations in the manure treatments were only slightly elevated over the control. The 2X urea rate of 100 kgN/ha applied the previous fall had the highest spring nitrate content. Low amounts and supply rates of soil nitrate in the cattle manure treatments, even the 2x and 4x rates compared to the swine manure reflect the slow release nature of the N in the cattle manure.
- Cattle manure addition resulted in much greater increases in the soil available P indices compared to swine manure. This is consistent with the higher P content of the cattle manure compared to the swine manure. The Kelowna extraction was not sensitive to the increase in P availability compared to the other methods used and its value as a predictor of P availability in manured soils may be questioned.

Dixon Cattle Manure 2004 Canola Yields

- As in 2003, the highest biomass yields were achieved at the highest rate of cattle manure addition (4x annual addition). These biomass yields of around 6000 kg / ha were similar to what was observed in the swine manure trial. The 4x-0-0 sequence (once every three years) yielded only about one half of the 4x-4x-4x (high rate every year), but was similar in yield to the 2x-2x-2x (medium rate every year). It appears that the high rate of cattle manure every year for the first few years is required to maximize yield, owing to the low N availability in this manure source. However, P loading will be of concern at these rates, and going to a 2x or 1x annual rate, or 4x every third year would be best, along with supplementation with commercial N fertilizer.

Soil Residual Nitrate

- Residual nitrate levels in the root zone 0-60cm were low and not significantly different among all manure treatments. The urea treatment did have higher nitrate in the root zone compared to other treatments. There was no significant difference among manure treatments in deep nitrate at 60-90, 90-120 and 120-150cm depths, but nitrate at 120-150 cm depth was significantly higher in the urea treatment, suggesting some deep leaching of fertilizer N. Overall, there appears to be very little risk of deep migration of nitrate with the cattle manure, likely owing to its wide C:N ratio and low rate of available N release.

2004 Melfort SWINE MANURE Plots with/without Added S Oats

Spring 0-15 cm depth Soil Characteristics After Manure Application the Previous Fall

- As expected, nitrate levels and supply rates in the soil increased in accordance with application rate of swine manure the fall before. Unlike all the other sites, application of swine manure did not significantly influence the supplies of available P measured by any of the methods. In fact, all the methods indicated that addition of manure or urea resulted in decreased soil P availability. This may reflect the low P content of the swine manure and/or immobilization of the applied manure P in the soil organic matter. Canola plants grown on the soils in the growth chamber appeared to exhibit some symptoms of P deficiency.

Melfort Swine Manure 2004 Oat Yield

- Yields were quite good even on the control plot, with 2600 kg/ha grain yield. This attests to the relatively high fertility of the Melfort soil. Annual application of swine manure resulted in near doubling of the oat grain yield to 4860 kg / ha, similar to what was achieved with commercial fertilizer. The 2x rate (6600 gpa) every second year produced yields similar to what was achieved with the 1x rate (3300 gpa) every year. The 3x rate 9900 gpa every third year also gave good yield in 2004, with the 2004 season being the second year following an application, so residual effects are evident.
- For the oat crop in 2004, the single application of sulfur made in the spring of 2002 did not have a significant effect on oat yield. This is explained by the residual effect of the sulfur application diminishing with time, as well as a lower S requirement by oat compared to canola grown in 2003. The swine manure supplied some sulfur to the crop, as reflected in increased sulfur concentrations and uptake in grain and straw. However the single applications of sulfate or elemental S in 2002 did not have a significant effect on S concentration in the plant in the 2004 oat crop, suggesting that the residual effect of the S fertilizer applications has diminished.

Soil Residual Nitrate

- At the Melfort site there were problems in obtaining cores from below the 90cm depth due to the presence of a gravel lens and due to missing data, statistics could not be run for the 90-120 and 120-160cm depths at this site. However, none of the treatments contained high levels of residual nitrate in the rooting zone 0-60cm, with the exception of the urea only treatment. Over the years, the urea only treatment has experienced low yields due to S deficiency which has led to accumulation of more nitrate in the soil profile. Furthermore, the urea only treatment shows evidence of nitrate leaching below 60cm. This trend is not evident in the treatment with the supplemental fertilizer sulfur, showing again that a balanced availability of nutrient is important to maximize utilization of all nutrients by the crop and prevent losses.

2004 Plenty SWINE MANURE Trials Canary Seed

Spring 0-15cm Soil Depth Characteristics After Manure Application the Previous Fall

- Repeated annual applications of manure at this site have resulted in very high nitrate accumulations in this soil, as discussed in 2003 data, with over 100 kg/ha of nitrate nitrogen in the top 15 cm of soil, even with reduced application frequency. It is important to note that the low rate for the first four years of the study was 5000 gpa and this was supplying about 200 kg N/ha per year. High rates of N addition coupled with crop failure in three years has resulted in high soil profile nitrates. Given the clay texture, there is relatively little leaching loss.
- The addition of swine manure resulted in increases in the soil available P as revealed for all indices used except the Kelowna extractable P, similar to that observed at the other sites.

Plenty Swine Manure 2004 Canary Seed Yields

- As observed in 2003, a single application of swine manure made in the fall of 1998 was still having a residual effect in 2004. The application rate of swine manure in fall of 1998 was about 150 kg N/ha at the low rate and 300 kg N/ha at the high rate. The high rate had significantly higher canary seed yield compared to the control. Overall, response of the canary seed yield in 2004 to manure and urea fertilizer applications was not high, as moisture limitations early in the season combined with frost later in the season restricted yield at this site. Furthermore, it has been documented that canary seed is not as responsive to N compared to other cereals. The highest yield occurred with the high annual rate of addition of swine manure, but this rate produced excessive levels of nitrate in the soil. As no response to increasing rate of fertilizer N was observed at this site, the increased yield from low to high rate of manure must be related to the manure supplying another nutrient or a non-nutrient benefit to the crop.

Soil Residual Nitrate

- Very high amounts of residual nitrate were found in the soil rooting depth (0-60cm) at this site, with the high annual application rate showing more than 1000 kg per hectare of nitrate. The low rate every year and the high rate every second year also showed high amounts (400 to 500 kg nitrate nitrogen per hectare) in the soil profile. The high rate applied every year and every second year showed some evidence of leaching into the 60-90cm depth, but there were no significant elevations below this depth that could be ascribed to leaching of manure nitrate. This is consistent with the high clay content and limited leaching regime in this soil that has been discussed previously.

2004 Riverhurst Irrigated SWINE MANURE YIELDS Seed Potatoes

Spring 0-15cm Soil Depth Characteristics After Manure Application the Previous Fall

- Similar to the Plenty site, which has the same comparison and history of rates and sequences of manure application as Riverhurst, the spring 2004 soil samples revealed significant accumulations of nitrate in the top 15 cm, with close to 200 kg nitrate nitrogen per hectare at the high annual application rate. Supply rates of nitrate to PRS anion exchange membrane (AEM) were also greatly increased by application of manure. Soil available phosphorus indices were also significantly elevated with manure application, with the exception of the Kelowna extractable P, as observed at the other sites.

Riverhurst Swine Manure 2004 Seed Potato Yields

- As at all the research trial sites, the field plots at Riverhurst were managed in the same way as the grower manages the rest of the field, with the exception of the manure applied the previous fall. Since it was not possible to control the pivot, all the Riverhurst plots received the same rate of nitrogen applied through the overhead pivot. Given the difficulty and inherent variability associated with harvesting tubers by hand for yield, there is a fairly high degree of variability among replicate treatments, making it difficult to reveal statistically significant differences among treatments.
- The unmanured check had the highest yield and the high rate of swine manure treatment had the lowest yield. The tuber yields of the manured treatments were significantly lower than the unmanured check treatment, suggesting that the manure whether applied annually, semi-annually or once every three years is having a negative effect on tuber yield, perhaps by supplying additional N that contributes to vegetative growth rather than tuber yield. From these data, it would be recommended to pay attention to available N levels in the soil following manure application when making decisions about the need for any additional nutrient to be supplied as fertilizer when growing potatoes.
- Of note is that despite the effect of the manure on lowering tuber yield, the addition of the hog manure resulted in significantly lower occurrence of

rhizoctonia disease compared to the check. This may be related to N nutrition, as the urea treatments also had lower incidence of rhizoctonia. Similarly, the addition of manure had a trend towards lowering the incidence of scab, although considerable variability was observed and the differences were not significant.

Soil Residual Nitrate

- Levels of residual nitrate in the profile at the Riverhurst site in the fall of 2004 were highly variable. This is explained in part by the extreme soil disturbance that accompanies potato production and harvest. Overall, nitrate was elevated at all depths including the 60-90cm and 90-120cm depths in the manure treatments and commercial N fertilizer. The large accumulations of nitrate at the 30-60cm depth observed in the fall 2003 sampling appear to have been moved down deeper by the irrigation in 2004
-

CONCLUSIONS PART A: Soil Nutrients and Crop Responses 2003 and 2004

After five to eight years of manure application at four SK sites using different rates, sequences and methods of application, the data are indicating that manure that is applied at rates that are in balance with crop removal and uptake over time is a sustainable management practice. In-soil placement of liquid swine manure by injection produces superior crop yield and nutrient recovery compared to surface application while minimizing odors. Additions of swine manure equivalent to about 100 lbs N/acre annually is capable of maximizing crop production with no apparent excess nutrient accumulation, toxicity or losses. Larger single applications made once every second or third year also do not appear to be associated with nutrient loading or large migration of nutrients out of the soil profile, but risk of nutrient loss or crop injury is greater in the year of application with a single high rate and the residual effects appear to have diminished significantly by the third year. Large additions made every year, e.g. 10,000 plus gallons per acre per year, result in excessive accumulations of nitrate and evidence of leaching below the rooting zone, as well as build-up of labile, potentially mobile phosphorus. For cattle manure, the build-up of nitrates at high rates of application after eight years was not apparent, reflecting the slow release of available N from the organic N forms in the manure. However, labile soil phosphorus was found to increase more rapidly in the cattle manure treatments than in swine manured soils and should be monitored closely.

Nutrient balances, especially N:S and N:P following manure application must be considered. No response to supplemental P fertilization was observed in the trials at Dixon in 2003 despite low amounts of P added as manure, but responses were observed in 2004 reflecting the variable nature of P response. Substantial responses to S fertilization applied in 2002 were observed with canola in 2003 on manured plots on a sulfur-deficient soil at Melfort, but no responses were observed with oats

in 2004, likely due to the diminished residual effect of the sulfur fertilizer application in 2002. Residual effects of manure applications made in past years on increasing availability of nutrients in the current year are very apparent, especially with cattle manure. These residual effects should be taken into consideration in manure nutrient management planning.

Applications of manure increased nitrogen, phosphorus and sulfur concentrations and uptake by crops, and the cereal and oilseed crops grown in 2003 and 2004: wheat, canola, oats responded well in increased yield and protein to manure application. The combination of manure with additional commercial fertilizer applied appeared to result in some reductions in potato tuber yield in irrigated potatoes that may be associated with excess nitrogen and should be explored further. Canary seed yield was not as responsive to manure as the other crops. At the Plenty site, accumulations of nutrient in the soil were highest, reflecting three years of low yield due to drought and insect accumulations. These results indicate the importance of matching manure nutrient application rate to crop growth and nutrient removal potential.

Part B: The Effects of Repeated Manure Applications on Selected Soil and Environmental Quality Parameters

Impact of Repeated Manure Application on Copper, Zinc, Cadmium, Selenium, Mercury and Arsenic in Soils and Plants.

Approach

Soils: Soil samples were collected in the spring of 2003 using 18cm long pieces of 10cm diameter polyvinyl chloride (PVC) pipe. Four cores were taken from each plot and later bulked together. Larger pieces of organic matter such as straw were removed from the top of the cores. The soil was stored at 4˚C and some was later air dried. The air dried soil was then passed through a fiberglass screen and a portion was ground using an agate mortar and pestle.

The ground soil was digested using microwave digestion in order to measure the total metal content of the soil. 10ml of nitric acid was added to 1g of soil in a teflon digestion vessel and then microwaved in stages until a set pressure of 120psi was reached. They were then kept at 120 psi for a length of time. After being allowed to cool, the digested samples were then made up to 50ml by weight with deionized water. A blank and a standard soil were included along with 10 samples in each batch.

The air dried soil was extracted using ammonium bicarbonate diethylenetriaminepentaacetic acid (AB-DTPA) (Lindsay and Norvell, 1978, Soltanpour and Workman, 1980) to measure the plant available pool of metals in the soil. The AB-DTPA solution was an aqueous solution of 0.05M DTPA, 1M NH_4HCO_3 and a few ml of NH_4OH to adjust the pH to 7.6. 40ml of AB-DTPA solution was added to 20g of soil and shaken for 15 minutes at 180 cycles/minute. The extracts were then filtered through Whatman 2 filter paper with suction applied to speed the process. An AB-DTPA

extraction was also performed on the soil that had not been dried using the same procedure.

Plant Material: Samples of the 2003 crop were collected at maturity. A $1m^2$ quadrat was harvested in each plot. The samples were allowed to air dry and the grain was separated from the straw. Straw samples were cut into <3cm pieces using brand new stainless steel scissors. The grain was not ground before digestion. Both grain and straw samples were digested using nitric acid microwave digestion. 10 ml of nitric acid was added to 0.5g samples of plant tissue in a teflon digestion vessel and microwaved in stages until a set pressure of 120psi was reached. They were then kept at that pressure for a length of time. A slightly different procedure was used for the canola grain samples to prevent a sudden pressure spike. After the acid was added the canola was allowed to sit in covered vessels at room temperature for 72 hours before microwaving. After being allowed to cool, the digested samples were then made up to 50ml by weight with deionized water. A blank and a standard plant leaf were included along with 10 samples in each batch.

Analytical: Copper, zinc, and AB-DTPA extractable cadmium were determined using atomic absorption spectrometry. Total cadmium levels in the soil and plant tissue were determined using a graphite furnace. The solutions were not altered in any way for copper, zinc, or cadmium analysis.
Total mercury levels in the soil and plant tissue were determined using the cold vapor hydride system. For mercury analysis, 1 ml of concentrated HCl was added to 8 ml of solution shortly after digestion was complete. AB-DTPA extractable mercury could not be determined due to the presence of mercury in the AB-DTPA solution itself.

Arsenic and selenium levels were determined using the hydride system with flame. After microwave digestion, 15ml of the digested soil solution or 30ml of the digested plant tissue solution was heated in teflon beakers on a hot plate to evaporate the nitric acid. 5 ml of water was added and evaporated 3 times to ensure that no nitric acid remained in the sample. Concentrated HCl was added to the beakers- 4 ml for the soil solution or 8 ml for the plant solution. The solution was then made up to a volume of 20 ml for the soil or 15 ml for the plant tissue. Additional HCl was added to the doubly digested soil solution before it was analyzed for selenium and arsenic. A few drops of urea solution was added before analysis in case any traces of nitric acid remained. Before arsenic analysis, .75ml of KI was added to 8ml of the doubly digested sample. The AB-DTPA solutions were acidified with HCl before being analyzed for selenium and arsenic.

Results and Discussion

A significant difference in total soil content, AB-DTPA extractable fraction, grain content and/or straw content was observed for some of the elements at some of the sites. In general, soil cadmium levels were not greatly affected by long term manure fertilizer addition, but plant cadmium levels did show changes with increasing fertilizer levels. At Dixon, no significant difference was seen in total or AB-DTPA extractable soil cadmium for various rates of hog effluent. However, as the manure fertilizer levels increased, the level of cadmium in the straw and grain grown on the treated plots increased significantly

(Table 1). An increase in plant cadmium levels with the addition of hog manure has been observed by Almas and Singh (2001) and they also observed an increase in the plant available cadmium fraction in the soil. Much of the increased cadmium uptake by crops growing on nitrogen amended soils is due to a soil pH drop caused by the fertilizer (Choudhary et al., 1994) along with enhanced uptake potential due to the fertilizer stimulating root growth.

Table 1 Soil and plant cadmium levels at Dixon under various hog effluent treatments. †

Treatment	Cadmium			
	Soil		Barley	
	Total‡	AB-DTPA§	Straw¶	Grain#
	mg kg^{-1}			
37,000 L ha^{-1}	0.374 a	0.237 ab	0.037 bc	0.005 bc
74,000 L ha^{-1}	0.411 a	0.235 ab	0.088 b	0.022 b
148,000 L ha^{-1}	0.392 a	0.238 ab	0.164 a	0.051 a
Urea, 112 kg N ha^{-1}	0.398 a	0.242 a	0.061 bc	0.013 b
37,000 L ha^{-1} broadcast and incorporated	0.369 a	0.215 b	-0.003 c	-0.007 c
Disturbed Check	0.380 a	0.216 ab	0.007 c	-0.007 c

† Values within a column followed by the same letter are not significantly different at p=0.05
‡ LSD = 0.0899
§ LSD = 0.0268
¶ LSD = 0.0636
 # LSD = 0.0189

Soil copper appeared to become more available to the plants as manure fertilizer application rates increased. Zinc followed a similar trend to copper at most of the sites. At Plenty, total and AB-DTPA extractable soil copper increased significantly at the highest rate of hog effluent application. Straw copper levels also showed a significant increase when fertilizer was applied. However, there was no trend in the level of copper in the grain (Table 2). While total soil and straw levels of zinc did not increase at Dixon under increasing cattle manure rates, soil AB-DTPA extractable and total grain levels of zinc did show a significant increase at the highest rate of cattle manure (Table 3). The differences in results for soil and grain copper and zinc levels are not unexpected as it has been shown that changes plant tissue content of these two elements do not necessarily correlate with changes in soil content of the elements (Mantovi et al., 2003).

Table 2 Soil and plant copper levels at Plenty under various hog effluent treatments. †

Treatment	Copper			
	Soil		Wheat	
	Total‡	AB-DTPA§	Straw¶	Grain#
	mg kg^{-1}			
37,000 L ha^{-1}	28.46 ab	5.38 b	2.79 a	7.62 a
74,000 L ha^{-1}	29.59 a	6.30 a	3.11 a	5.52 ab
Urea, 80 kg N ha^{-1}	27.71 b	5.09 b	2.56 a	4.98 b
Disturbed Check	27.92 b	5.35 b	1.90 b	5.83 ab

† Values within a column followed by the same letter are not significantly different at p=0.05
‡ LSD = 1.49
§ LSD = 0.547
¶ LSD = 0.655
 # LSD = 2.52

Table 3 Soil and plant zinc levels at Dixon under various cattle manure treatments. †

Treatment	Zinc			
	Soil		Barley	
	Total‡	AB-DTPA§	Straw¶	Grain#
	mg kg^{-1}			
37,000 L ha^{-1}	78.04 a	3.68 b	11.11 a	32.22 ab
74,000 L ha^{-1}	76.50 a	5.22 a	13.33 a	32.22 ab
148,000 L ha^{-1}	75.23 ab	5.99 a	11.74 a	38.86 a
Urea, 112 kg N ha^{-1}	70.95 b	2.52 c	7.45 a	32.39 ab
Disturbed Check	73.71 ab	2.01 c	11.27 a	28.71 b

† Values within a column followed by the same letter are not significantly different at p=0.05
‡ LSD = 5.482
§ LSD = 1.110
¶ LSD = 5.947
 # LSD = 7.334

Few or no significant differences were found in arsenic, selenium, and mercury levels in the soil and plant tissue at the various sites. At Riverhurst, there were no significant differences in total or available soil arsenic or total arsenic in the straw. There may be a significant increase in grain arsenic at Riverhurst at the highest manure application rate, however as the readings for the other three numbers are negative values this may just be an experimental artifact or instrumental error (Table 4). The low level of arsenic found in the plant tissue is what one would expect to see as even on contaminated soil, plants usually have only a low concentration of the element (McLaughlin et al., 2000). There were no significant differences in total soil, straw, or grain mercury levels at Plenty (Table 5). Again, the low plant tissue mercury levels were expected as mercury

accumulation in plants is not usually a problem (McLaughlin et al., 1996). At Melfort, there were no significant differences in total soil, straw or grain selenium levels (Table 6). The lack of significant difference in plant selenium content is somewhat surprising, although it could be attributed to the level of selenium in the hog effluent (0.083 mg kg^{-1} at Melfort) not being great enough to influence the soil and plant contents of the element.

Table 4 Soil and plant arsenic levels at Riverhurst under various hog effluent treatments. †

Treatment	Arsenic			
	Soil		Wheat	
	Total‡	AB-DTPA§	Straw¶	Grain#
	mg kg^{-1}			
37,000 L ha^{-1}	3.73 a	0.055 a	0.095 a	-0.024 ab
74,000 L ha^{-1}	3.48 a	0.058 a	0.119 a	0.003 a
Urea, 80 kg N ha^{-1}	3.68 a	0.053 a	0.071 a	-0.014 ab
Disturbed Check	3.74 a	0.047 a	0.040 a	-0.030 b

† Values within a column followed by the same letter are not significantly different at p=0.05
‡ LSD = 0.342
§ LSD = 0.0305
¶ LSD = 0.0804
 # LSD = 0.0297

Table 5 Soil and plant mercury levels at Plenty under various hog effluent treatments. †

Treatment	Total Mercury		
	Soil‡	Wheat	
		Straw§	Grain¶
	mg kg^{-1}		
37,000 L ha^{-1}	0.018 a	0.012 a	0.004 a
74,000 L ha^{-1}	0.020 a	-0.017 a	0.003 a
Urea, 80 kg N ha^{-1}	0.012 a	-0.002 a	0.004 a
Disturbed Check	0.012 a	-0.017 a	0.003 a

† Values within a column followed by the same letter are not significantly different at p=0.05
‡ LSD = 0.0037
§ LSD = 0.0384
¶ LSD = 0.0028

Table 6 Soil and plant selenium levels at Melfort under various hog effluent treatments. †

Treatment	Total Selenium		
	Soil‡	Canola	
		Straw§	Grain¶
	mg kg^{-1}		
37,000 L ha^{-1}	0.809 a	0.276 a	0.97 a

74,000 L ha^{-1}	0.734 a	0.609 a	1.02 a
Urea, 80 kg N ha^{-1}	0.770 a	0.578 a	N/A#
Disturbed Check	0.846 a	0.914 a	2.03 a

† Values within a column followed by the same letter are not significantly different at p=0.05
‡ LSD = 0.0833
§ LSD = 0.9195
¶ LSD = 1.233
# The urea treatment did not yield enough grain to test.

SUMMARY Of TRACE METALS:

Overall, after five to eight years of repeated manure application, the accumulation of trace metals appears to be limited to some relatively small increases in labile copper and zinc. There was no evidence for accumulation or toxicity of non-functional trace metals like mercury or arsenic.

Early Crop Growth and Soil Physical Properties as Influenced by Repeated Manure Application.

Approach

Soil Strength: A recording cone penetrograph (Eijkelkamp Agrisearch Equipment, The Netherlands) was used to measure soil strength to 20cm depth on the Dixon plots on May 28, June 16 and September 8, 2003. Five sub-samples were taken per plot. Soil moisture has an inverse influence on soil strength. Increased soil moisture will have decreased soil strength compared with the same soil at a lower moisture content. Therefore, gravimetric soil moisture was determined from five soil samples taken to 15cm depth at each sampling location. However, due to the small plot size, only three soil samples were taken in the cattle manure trial. Soil moisture has a direct influence on soil resistance.

Emergence: Plant counts using 0.25m^2 quadrats were taken May 28 at Dixon, at approximately the 3 leaf stage of the barley. Five sub-samples were taken per plot on the hog manure trial, while 3 were taken on the cattle manure trial.

Aggregate Mean Weight Diameter: A separate set of surface soil samples was taken with a shovel from the five manure trials in late April 2003 and dried to air dry moisture content. A rotary sieve with seven size fractions was used to determine the mean weight diameter of the aggregates.

Rainfall Simulator: Soil cores (18cm, 15cm diameter) were taken from all the field trials at the end of April, 2003. Soil cores from select locations in southern Saskatchewan were also taken in May 2003. All soils were dried intact to air-dry moisture content.
The interaction between treatment and potential crust formation was examined using a Guelph Rainfall Simulator II (Tossell et al., 1987), as heavy rainfall will enhance surface

crust development. The simulator was calibrated with 8 rain gauges spread in a 1m·1m square. Using the formulas provided by Tossell et al. (1987) rainfall intensity and uniformity were tested on three different nozzles were tested. The 1/4GG 14W nozzle (Spraying Systems Co., Wheaton Ill.) was found to be suitable, with a rainfall intensity of approximately 91mm h^{-1} with 85% uniformity. The other nozzles had poor uniformity (1/4GG 10W) and inconsistent rainfall intensities (1/8GG 4.3W).

Canola and flax were used as test crops to indicate the treatment effects of soil crust strength on seedling emergence. Canola and flax were chosen because they are small seedlings with low seed vigour and therefore sensitive to crust formation. The soil cores were fitted with cheesecloth around the base and supported by expanded metal to prevent soil loss. Ten canola seeds were placed in one half of each core. The other half of the core was reserved for penetrometer measurements.

Cores were weighed at air dry moisture content. A rainfall of 20 minutes was applied using distilled water. Water samples were taken from all rainfall events and the EC was tested. After the rainfall event, the cores were weighed, covered with an aerated plastic bag to reduce evaporative losses, and placed in a growth chamber set to a 14 hour, 18°C day and an 10 hour, 12°C night. The cores were re-randomized every day after sampling. A CL-700 pocket penetrometer (Soiltest Inc., Chicago, USA) was used to measure the crust strength of the soil each day for 10 days. Canola plant counts and soil weights (to account for water loss) were also taken each day. A rating of the canola plants emerged was conducted after the experiment.

The rainfall simulator experiment was then repeated for flax. The soil cores were rained on for seven minutes, and then placed in the growth chamber to dry down overnight. This softened the surface so that flax could be seeded without difficulty. The flax was seeded to 2cm depth and then the soil surface was pressed down 0.5cm to seal the hole. The rainfall duration was reduced to 15 minutes. Sampling began on the third day after the rainfall. After the experiment, the flax and weeds were harvested so the dry weight could be determined. Samples were dried to a constant moisture content at 50°C.

Infiltration: A watering system was devised to supply a constant rate of water to the soil cores to measure infiltration times. Extensions were added to the soil cores so water could pond. The water fell from a height of 12.5cm above the core extension. Measurements were made to determine how fast water ponded on the surface, the time when the water reached the desired level and the time when the water had infiltrated. Some samples did not work well for this experiment as water would run down the sides of the core, making the results difficult to interpret. At the end of the experiment the soils were processed and analyzed for electrical conductivity, exchangeable sodium percentage, modulus of rupture and coefficent of linear extensibility.

Results and Discussion

Soil Strength

Usually, when soil strength reaches a value of 2.0Mpa or greater, root growth inhibition begins. However, this varies depending on crop and soil type. Taylor et al. (1966) found that 2.5MPa was the extreme limit at which no roots penetrated, while at 1.9MPa, root penetration was good. Moisture content influences soil strength, high strength with low soil moisture and low strength with high soil moisture content.

The May 28, 2003 field sampling is likely most representative of the soil strength conditions as it would affect plant growth, as affected by the manure before the impact of differential plant growth between treatments itself influences strength (Figure 1). For example, vigorously growing plants would utilize more soil moisture, increasing the soil strength. The control treatment consistently had the greatest soil strength, although differences were not significant at the 10cm depth. At the 15 and 20cm depths the control treatment was significantly higher than only that of the high rate of manure.

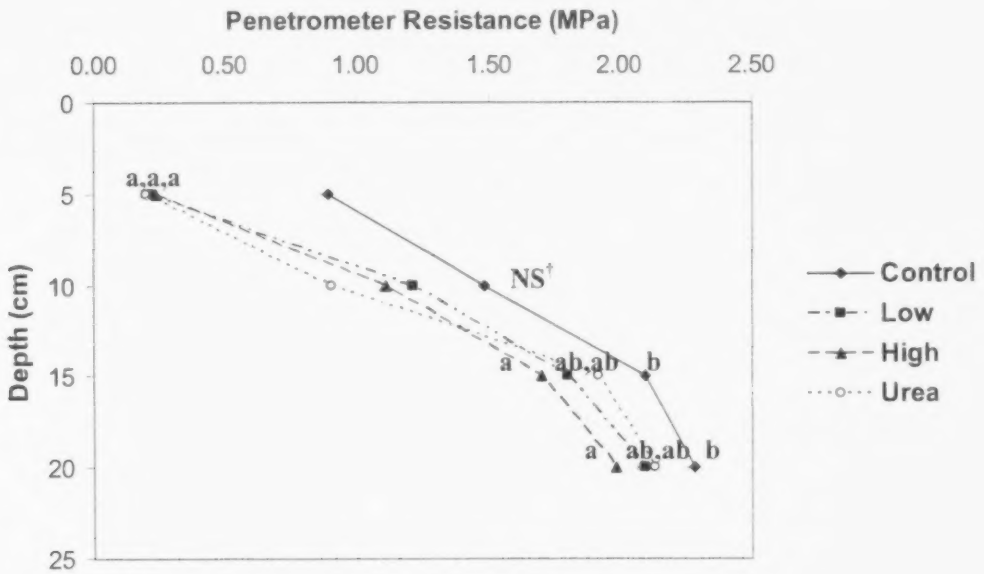


Figure 1 Penetration resistance (soil strength) in four treatments as measured on May 28, 2003 at four different depths in a barley crop at the Dixon, SK swine manure trial.

* Points with the same letter are not significantly different at the 90% confidence level.

† No points are significantly different.

Since 1997, the control treatment has had reduced crop biomass due to declining fertility (Mooleki et al., 2002). The difference in the amount of biomass returned to the soil and lower organic matter (King et al., 2004) could explain why the control treatment had significantly higher soil strength. In support of this concept, the manure treatments also never significantly differed from the urea treatment.

The June 16 sampling was an assessment at a more advanced stage of crop growth in the plots. The low rate of hog manure had the greatest resistance at the 15 and 20cm depths. Both the low rate hog manure and the urea fertilizer treatment were significantly higher than the control at the 5 cm depth. The impact of crop growth is more of a consideration at the June 16 sampling date. The control tended to have the highest water content due to poor moisture use from lack of fertility and the low rate manure and urea treatments had the lowest water content, indicating greater water usage by the crop due to better crop growth. The final grain yields also confirm this observation, as the low (agronomic rate) swine effluent yielded 3708kg ha^{-1}, while the high rate and urea treatments were 3375kg ha^{-1} and 3000kg ha^{-1} and the control was 1570kg ha^{-1}.

The penetrometer resistance measured after harvest in September 2003 showed higher resistance at depth than the earlier samplings, likely due to moisture removal by the crop and increased root biomass. At the 5 and 10cm depths, the control treatment had greater soil strength than other treatments, possibly due to evaporative losses near the surface. The high rate manure and urea fertilizer treatments had greater resistance at depth, perhaps due to greater water uptake by the crop.

Field Emergence

Plant emergence of the barley at the Dixon site showed no statistical differences between the manure treatments and the control (Table 1). However, the high rate of manure tended to be lower than the low rate and was significantly lower than the urea treatment. This may be indicative of a salt effect from the excessively high rate of manure causing reduced emergence. However, the difference does not seem to be biologically critical.

Table 1 Barley Emergence at the 2-3 Leaf Stage at Dixon, 2003.

Treatment	Emergence
	----Count per 0.25m^2----
Control	38.02a
Low Manure Rate	42.90ab
High Manure Rate	38.30a
Urea	46.35b

SUMMARY OF EARLY CROP DEVELOPMENT:

In the field, early crop growth and development was not significantly influenced by a history of repeated annual applications of swine manure, especially at agronomic rates. However, care must be taken when seeding crops into soils that have received high rates of liquid manure that year and in which there has been limited leaching, as salts and ammonium from the manure may be present in the seeding zone that could interfere with germination and early plant development, especially under dry conditions.

Aggregate Mean Weight Diameter

The manure treatments tended to have smaller aggregate sizes at the Dixon hog manure and Melfort sites (Table 2). Severe sulfur deficiencies decreased crop growth in the urea fertilizer treatment at Melfort. No change was detected at Plenty or Riverhurst. Overall, the effect was small.

Table 2 Aggregate MWD for research sites. Standard deviations are shown in parentheses.

Treatment	Plenty	Riverhurst	Melfort	Dixon Cattle	Dixon Hog
			----------mm----------		
Control	6.6 (0.5)	8.9 (1.0)	13.5 (1.0)	n/a	8.9 (1.0)
Low	7.2 (1.3)	8.7 (1.0)	12.7 (1.9)	8.2 (1.5)	7.3 (0.9)
High	7.1 (0.6)	8.6 (0.3)	11.2 (1.6)	9.5 (0.6)	8.5 (1.0)
Urea	7.2 (0.6)	8.0 (0.6)	10.9 (1.2)	n/a	9.1 (1.0)

Crusting Induced by Rainfall Simulator

Canola Experiment

Arndt (1965) determined that seedlings can tolerate up to 0.63 to 0.94MPa dry soil crust strength before emergence begins to suffer. The crust strengths at the Melfort site were well below this critical level. This was also true at the Riverhurst site as well. Both low and high rate manure treatments tended to have lower crust strength than the control or urea treatments. The effect of different treatments become most pronounced seven to eight days after the rainfall event. The magnitude of crust strength at Melfort is higher than that of the Dixon hog manure trial. The low rate of hog manure had the greatest crust strength at the Dixon hog manure trial, while the high rate tended to be the lowest. This was similar to the results from Plenty. The high manure rate has an aggregate MWD similar to the control and urea fertilizer treatments at the Dixon site. The low manure treatment has a lower aggregate MWD. Additionally, the crust strengths measured in the Plenty and Dixon soils were very low, with a range of only 0.06MPa between highest and lowest, compared with 0.15MPa in Riverhurst and Melfort soils.

Plant Emergence as Affected by Crust Development after a Simulated Rainfall

Some problems with seeding the canola made trends difficult to determine, therefore the flax experiment is likely more representative of field conditions. The Melfort site had very poor emergence with a lower proportion of seeds germinating. The Melfort soil cores did not take on as much water as the others. All the other cores gained approximately 600g after the rainfall simulation, while Melfort soils gained only 200-300g. The lower water content of the soil delayed germination beyond the measurement period.

The Dixon swine manure trial had similar emergence among treatments. The urea fertilizer treatment had the poorest emergence. The manure treatments had greater emergence, but the control treatment resulted in the best emergence. The salt effect from

the manure may be having an influence, similar to findings in the field for barley emergence.

Infiltration

The Riverhurst soils performed best in this assessment as there was very little disruption and macropore development along the interface of the core and soil. The control treatment had the fastest infiltration, but the low rate manure treatment had fast infiltration as well. The urea fertilizer treatment took the longest to infiltrate. After the infiltration was complete, visual observation indicated that little, if any surface structure remained and the surface aggregates had been destroyed. The urea fertilizer treatment had the slowest infiltration on all sites except Plenty, where the control treatment was slowest. The other sites showed the manure treatments to have faster infiltration.

Salinity, Sodicity and Modulus of Rupture

Following the simulated rainfall experiments on the soil cores, salinity (electrical conductivity), sodicity (exchangeable sodium as a percentage of the total cation exchange capacity) and modulus of rupture (crusting) were measured (Table 3).

Table 3. Salinity, sodicity and crusting measured in soils from manure treatments collected from the field trial plots and subjected to simulated rainfall in the laboratory.

	Trt	EC		ESP		Modulus of Rupture		COLE	
		mean		mean		mean		mean	
Plenty	1	0.21333	b	1.38670	a	0.65670	a	0.05167	a
	2	0.27867	ab	1.70330	a	0.48330	a	0.05667	a
	3	0.32267	a	2.00330	a	0.00000	a	0.01500	a
	5	0.21500	b	1.35330	a	0.00000	a	0.00000	a
	LSD (0.05)	0.10410		0.69720		1.51890		0.05800	
	N	3		3		6		6	
Riverhurst	1	0.23133	c	2.56670	a	1.03800	a	0.03667	a
	2	0.36133	ab	2.72670	a	0.60500	a	0.02500	a
	3	0.39733	a	2.91670	a	0.00000	a	0.01333	a
	5	0.27767	bc	2.58670	a	1.84700	a	0.03833	a
	LSD (0.05)	0.10730		0.55250		2.96120		0.03870	
	N	3		3		6		6	
Melfort	1	0.29000	a	1.00667	b	0.73670	a	0.02000	ab
	2	0.37033	a	1.14000	a	0.00000	a	0.02000	ab
	4	0.40267	a	1.24333	a	1.40330	a	0.03667	a
	5	0.28400	a	1.00000	b	0.00000	a	0.00833	b
	LSD	0.12390		0.12970		2.03230		0.02640	

	(0.05)								
	N	3		3		6		6	
Dixon Hog	2	0.25300	a	1.23250	b	0.89180	a	0.03550	a
	4	0.33875	a	1.60000	a	0.00000	a	0.00813	ab
	9	0.35700	a	1.73500	a	0.00000	a	0.01275	ab
	14	0.27475	a	1.21750	b	0.00000	a	0.00700	b
	LSD (0.05)	0.14200		0.33730		1.42640		0.02830	
	N	4		4		8		8	
Dixon Cattle	3	0.40630	a	1.41670	a				
	8	0.63430	a	1.51000	a				
	LSD (0.05)	0.48440		0.45150					
	N	3		3					
EC denotes Electrical Conductivity in mS/cm									
ESP denotes Exchangeable Sodium Percentage									
COLE denotes Coefficient of Linear Extensibility.									

SUMMARY OF PHYSICAL PROPERTIES:

Soils from the trials with a history of five to eight annual manure applications showed no apparent increases in salinity or sodicity associated with the manure applications at either low or high rates. Consistent with this was the observation that surface crusting was either not affected or reduced with manure application and that water infiltration was not affected or sometimes increased in the manured soils. In general, repeated manure application at agronomic rates was found to have no detrimental impact on early crop growth or soil physical properties.

Impact of Repeated Additions of Manure on Soil Organic Carbon and Soil Biochemical Properties.

Approach

Soil Sampling: Soil samples were taken from all plots at Dixon on April 22.2003, Melfort on April 25, 2003, Riverhurst on April 28, 2003 and Plenty on April 30, 2003. Soil

samples were taken at Dixon approximately 2 weeks prior to liquid manure and urea fertilizer application. The other sites had the liquid swine manure and urea fertilizer applied the previous fall. Samples for the Dixon, Riverhurst and Plenty liquid swine manure plots were taken 5 m in from the north end and in the middle of each plot. Soil samples for the Melfort site were taken 5 m in from the west end and in the middle of each plot. Soil samples for the Dixon cattle manure plots were taken in the center of the plots. Soil samples were taken using polyvinylchloride (PVC) pipes measuring 15 cm in height and 10 cm in diameter. Four PVC cores were inserted per plot. The PVC cores were inserted by setting on the soil surface and pushing them into the soil. The cores were then removed by excavation, bagged, tagged, removed from the site and stored at in a refrigerated facility at 4 ^{O}C for analysis. Soil was removed from the cores, bulked , mixed and half the sample was placed in plastic bags and refrigerated at 4 ^{O}C for microbial analysis. The other half of the soil sample was air dried, ground to pass a 2-mm sieve and stored in labeled plastic bags at 20 ^{O}C, or room temperature.

Total Soil Organic Carbon: The soil organic carbon contents of soil samples of approximately 0.15 g, previously ground with a ball mill to pass a 100-mesh sieve, were measured by the dry combustion method using the LECO CR-12 Carbon Analyzer set at 840 ^{O}C. The LECO CR-12 Carbon Analyzer for C determination is capable of complete recovery and high precision, and is recommended for the total organic carbon analysis of soil and mineral samples (Wang and Anderson, 1998).

Light Fraction Organic Carbon: The light fraction component of the organic carbon in the soil samples was determined using the method developed by Gregorich and Ellert (1993). The 0-15 cm increment of each soil core was selected for LFOC analysis as this layer is the most sensitive to LFOC changes induced by recent additions of organic matter from forage and/or grass biomass and from additions from injected hog manure. Twenty five grams of air dried and 2mm sieved soil samples were weighed into 110 ml centrifuge tubes and 50 ml of sodium iodide (NaI) (USP grade) of density 1.7 g cm^{-3} was added to each tube, covered, shaken for 60 minutes, and centrifuged at 1000 X gravity for 20 minutes. The NaI containing the light fraction was decanted from the tubes and put through a millipore filter. The light fraction on top of the filter was then rinsed with 0.01 M calcium chloride ($CaCl_2$) to remove all the NaI. Iodine may interfere with carbon analysis and $CaCl_2$ prevents the clogging of the filter (Mensah et al., 2003). The light fraction was then rinsed with deionized water to rinse and remove all the $CaCl_2$ from the light fraction. The light fraction was then collected and dried for 72 hours at 45 ^{O}C to obtain the dry weight. The concentration of organic carbon in the light fraction was determined using the LECO CR-12 Carbon Analyzer as described in the previous section.

Results and Discussion

Table 1 . Mass of **soil organic carbon** in the 0-15 cm depth at four Saskatchewan sites in 2003.

Treatment	Dixon Hog	Dixon Cattle	Melfort	Riverhurst Irrigated	Plenty

	Mg ha^{-1}				
Check	48.6	53.5	68.7	32.6	25.8
Low	50.7	54.6	67.1	33.1	28.7
Medium	47.2	55.3	67.3	29.9	28.8
High	49.4	55.6	NA	NA	NA
B&I Low	46.2	NA*	NA	NA	NA
Urea	50.8	53.35	61.7	29.9	29.3
$LSD_{(0.10)}$†	NS‡	NS	4.2	2.5	2.8

†Least significant difference at α=0.10.
‡NS: Not significant at a = 0.10.
*NA: Treatment not applicable at this site.

Treatment	Dixon Hog	Dixon Cattle	Melfort	Riverhurst Irrigated	Plenty
	Mg ha^{-1}				
Control	2.10	3.08	1.84	1.88	0.92
Low	2.51	5.28	2.68	3.02	1.64
Medium	2.32	4.19	3.13	1.47	1.73
High	2.68	5.44	NA	NA	NA
B&I Low	2.41	NA*	NA	NA	NA
Urea	2.53	2.91	2.64	1.88	1.49
$LSD_{(0.10)}$†	NS‡	NS	1.03	0.38	0.48

Table 2 Mass of **light fraction organic carbon** in the 0-15 cm depth at four Saskatchewan sites in 2003.
†Least significant difference at α=0.10.
‡NS: Not significant at a = 0.10.
*NA: Treatment not applicable at this site.

Dixon Site

Soil Organic Carbon

The application of liquid swine manure had no significant impact at p = 0.10 on SOC levels in the 0-15 cm depth. The low swine manure rate increased SOC levels from 48.6 Mg ha^{-1} in the control plot to 50.7 Mg ha^{-1}, however, the SOC level in the urea treatment was 50.8 Mg ha^{-1} . There could be several reasons why there was not a significant effect on SOC mass at this site. The liquid swine manure was not applied until early May of 2003, after the soil samples had been taken. The last application of liquid swine manure was in the fall of 2001, thus it had been 19 months since an application of manure and urea fertilizer had been made. The drought greatly reduced the flax grain and straw production in 2002. Although the manure and urea fertilizer stimulated increased

straw production at Dixon from 1997 to 2002 (Mooleki et al., 2002) the increased C inputs did not produce a statistically significant increase in total soil organic carbon.

Soil organic carbon levels for the solid cattle manure treatments showed no significant differences at the $p = 0.10$ level amongst the treatments. The medium cattle manure treatment showed the greatest amount of SOC at 55.3 Mg ha^{-1} versus 53.5 Mg ha^{-1} for the control treatment. At the Dixon site, solid cattle manure was not applied for the 2003 crop year until May 2003, several weeks after soil samples were taken. The cattle manure study is located on the same field site as the swine manure study and the flax crop was thus subject to the same drought conditions that affected the entire field site.

Light Fraction Organic Carbon

Light fraction organic carbon levels in the Dixon liquid swine manure plots were not significantly different among the six manure and urea treatments. The mean LFOC levels increased from 2.10 Mg ha^{-1} in the control plot to 2.51 and 2.68 Mg ha^{-1} in the low and high liquid swine manure treatments, respectively. Light fraction organic carbon is comprised of recent additions of organic material to the soil surface (Gregorich and Ellert, 1993). Since the Dixon site produced very low amounts of crop growth in the previous year due to drought, this would have also impacted the amount of light fraction carbon that would be recently formed in the soil by above ground (crop residue biomass) and below ground materials (root biomass).

The LFOC in the solid cattle manure treatments showed the same pattern as the liquid swine manure, in that LFOC levels increased from 3.08 Mg ha^{-1} in the control to 5.28 and 5.44 Mg ha^{-1} in the low and high cattle manure treatments, respectively. Cattle manure is more than 20% or more solid material, which adds directly to the soil organic matter as opposed to liquid swine manure which on average contains less than 2% solids (Schoenau, 2003). A larger effect of adding cattle manure on LFOC than liquid swine manure is anticipated since the cattle manure would contribute directly to the LFOC through direct solid material addition. Liquid swine manure would contribute indirectly to LFOC by the increase in plant biomass through nutrient uptake form the liquid manure. Subsequent incorporation into the soil, microbial decomposition and breakdown of plant biomass would then add to the light fraction organic carbon.

Melfort Site

Soil Organic Carbon

Soil organic carbon levels at the Melfort site for the control, low and medium liquid swine manure treatments were significantly higher than the SOC levels for the urea treatment (61.7 Mg ha^{-1}). However, SOC levels for the low and medium rate manure treatments were lower than the 68.7 Mg ha^{-1} in the control. The urea application at 80 kg ha^{-1}resulted in the lowest canola grain yield (King et al., 2004) Plots receiving only urea fertilizer exhibited signs of sulfur deficiency (Schoenau et al., 2003). The sulfur deficiency could have limited canola grain production in the urea plots. In 2002, the grain yield of the oats crop was increased by application of swine manure and urea, however,

there was no significant response to swine manure rate, most likely as a result of dry conditions (Mooleki et al., 2003). This could have resulted in lower amounts plant biomass being produced which in turn could have limited the amount of biomass materials that eventually were incorporated into the soil to be decomposed by microorganisms. The medium treatment was not applied in the fall of 2001, thus the plants in that treatment were utilizing the nutrients left over from the previous year or were also utilizing nutrients mineralized from the manure over the winter and spring of 2002 to aid in growing the oat crop. This would have increased crop biomass production, which in turn would have led to more SOC being returned to the soil.

Light Fraction Organic Carbon

The LFOC for the medium swine manure treatment was significantly higher than the control. The medium manure treatment produced 3.13 Mg ha^{-1} of LFOC, while the control produced 1.84 Mg ha^{-1} of light fraction carbon. The carryover of nutrients from the previous year's application of manure aided in producing more plant biomass. Despite there being no significant difference in SOC values between the control plots and the two rates of liquid swine manure, the LFOC is reflecting recent additions of organic matter and can serve as a future predictor of what will eventually occur on a field site with regards to SOC levels (Gregorich and Ellert, 1993).

Riverhurst Site

Soil Organic Carbon

Soil organic carbon levels at Riverhurst were significantly higher for the control and low liquid swine manure rate versus the high manure rate and urea rate. The high manure rate and urea each had 29.9 Mg ha^{-1} of SOC, while the control and low manure rate had 32.6 and 33.1 Mg ha^{-1}, respectively, of soil organic carbon. This site experienced a grasshopper infestation in 2002. The low crop biomass production would have added only a small amount of plant biomass to the soil for the 2002 year.

Grevers (2002) reported that drought conditions and grasshopper problems in 2001 and 2002 caused low crop yields and yield response to swine manure and urea fertilizer applications. Grevers (2002) also reported that the 1999 crop was seeded to beans and resulted in a limited response to the two rates of manure and urea fertilizer. As well, at this site the straw is removed as bales each year. The author also reported that there was no yield advantage in applying swine manure at the high rate. The high rate of swine manure is considered to be agronomically excessive and can result in damage to a crop (Grevers, 2002; Mooleki et al., 2002). The limited crop response to the application of swine manure at the Riverhurst site would have resulted in lower amounts of plant biomass being produced. This subsequently would add very little organic material to the SOC pool and result in no significant change in SOC levels between the manure and urea treatments.

Light Fraction Organic Carbon

Light fraction organic carbon levels were the same for the control and urea fertilizer plots, and were significantly lower than the LFOC for the low treatment. The low liquid swine manure treatment produced 3.02 Mg ha^{-1} of LFOC versus 1.88 Mg ha^{-1} for both the control and urea fertilizer treatments. The LFOC for the low manure treatment is following the same pattern as the SOC in that both LFOC and SOC levels were the greatest (3.02 and 33.1 Mg ha^{-1}, respectively) for the site under this treatment. The low swine manure treatment is showing greater amounts of SOC versus the other treatments and the LFOC is showing that there will be greater additions of organic carbon to the overall SOC level in the soil.

Plenty Site

Soil Organic Carbon

Soil organic carbon levels were significantly higher in the low and high rate liquid swine manure treatments versus the control plots. The low and high swine manure treatments produced 28.7 and 28.8 Mg ha^{-1}, respectively, versus 25.8 Mg ha^{-1} in the control plot. The urea fertilizer treatment also produced significantly higher SOC versus the control plots, although the SOC in the urea fertilized plots was not significantly different from the two rates of swine manure. The Plenty site has received low amounts of precipitation since the swine manure trials began in 1999. Grevers (2002) reported that the 2000 and 2001 crop suffered from drought and that there was a complete crop failure in 2002. Low inputs of moisture would restrict crop biomass production, which in turn would limit the amount of plant biomass that is incorporated back into the soil. This would limit the inputs to SOC and light fraction carbon. However, the Plenty site has low amounts of soil organic matter and high clay content. Therefore there is a capacity to build up the pool of SOC and light fraction organic carbon.

Light Fraction Organic Carbon

The LFOC levels for the two rates of liquid swine manure were significantly higher at the $p = 0.10$ than the control LFOC levels, but not significantly different from each other. Light fraction organic carbon levels were 1.64 and 1.73 Mg ha^{-1} for the low and high manure treatments, respectively, while the control LFOC was 0.92 Mg ha^{-1}. The urea fertilizer LFOC (1.49 Mg ha^{-1}) was significantly different from the control, however, it was not significantly different from the two rates of swine manure. The LFOC for the two rates of swine manure followed the same pattern as for the SOC levels for both rates of manure. The significant difference in LFOC between the two rates of swine manure and the control show that in the future, there should be greater increase in SOC levels receiving liquid swine manure, versus the untreated control plots.

There was no significant difference in LFOC between the two rates of swine manure and the urea fertilizer, although the urea fertilizer showed lower levels of LFOC. The lack of significant difference between the manure and urea fertilizer could be due to the fact that all the crops at Plenty from 2000, 2001 and 2002, suffered from drought conditions which limited grain and straw production.

Four Saskatchewan Site Comparisons of SOC and LFOC

Data from the swine and cattle manure trials at the four sites show that the Melfort site has the greatest amount of SOC, but a lower amount of LFOC, compared to the other three sites. Soil organic carbon in the control plots at Melfort is 68.7 Mg C ha-1, while the Plenty site (control plots) has the lowest amount of soil organic carbon. The Melfort plot is located in the Gray-Black soil climatic zone and would thus have more SOC reserves, since this area traditionally receives greater amounts of moisture than the Plenty and Riverhurst sites. The Plenty site (Brown soil zone) has the lowest level or less than half the amount of SOC as reported at the Melfort site. The Plenty site surface texture is a clay to heavy clay. At the Riverhurst site, the application of swine manure is reported (Grevers, 2002) to have improved soil structure on the coarse textured sandy-loam soil and that this site benefited more from the application of swine manure.

Application of swine manure at the Dixon site increased grain biomass production over the first four years of the study (Mooleki et al., 2002). Soil organic carbon values were not significantly different between the control plots and the three rates of swine and cattle manure. There could potentially be enhancement of microbial activity by the added nutrients that results in more rapid decomposition of plant biomass organic matter additions to the soil (Eiland, 1980). A trend towards higher enzyme activity with manure application at this site would tend to support this idea.

Microbial Enzyme Activity

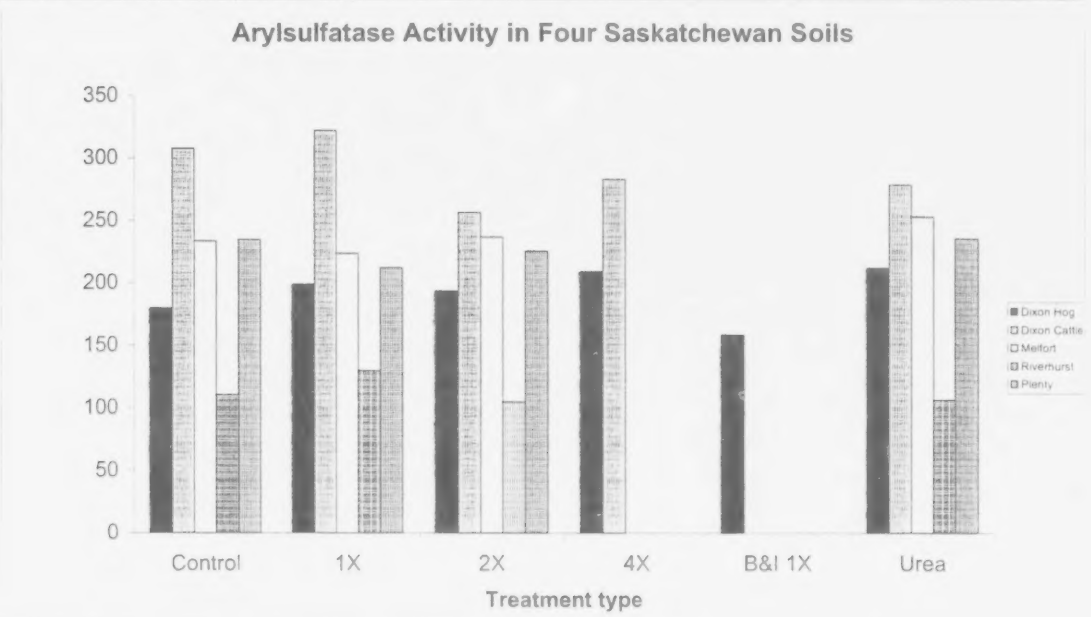


Figure 1

Microbial enzyme activity was influenced to a greater degree by site location than by manure application. For example (Fig1), arylsulfatase enzyme activity was greatest at Melfort and Plenty sites. These two sites have high clay contents and clay is known to protect enzymes from decomposition. Overall, the addition of manure had relatively little impact on the enzyme activity, which may be due to measurement of enzyme activity in soil samples collected in the spring about six months after the manure was applied the previous fall. The agronomic rate of manure (1X) tended to have enzyme activities that were similar or higher than the other treatments. As enzymes produced by microorganisms are important in promoting many transformations important in nutrient cycling, it appears that manure addition will either sustain or enhance many of these microbial transformations.

SUMMARY OF ORGANIC MATTER AND BIOCHEMICAL PROPERTIES

Increases in soil organic matter content associated with five to eight years of annual swine manure additions are not large, and are mainly related to enhanced crop growth and residue input, that shows up as increased light fraction organic carbon. Compared to solid manures, liquid swine manure adds relatively little organic matter directly. As the nutrients will stimulate microbial activity and enhance deomposition, there may a counteracting effect and it may take many years before significant increases are observed. Microbial enzyme activity appears to be relatively unaffected or enhanced by manure application at agronomic rates, suggesting enhanced nutrient recycling rates.

General Conclusion for Part B: Metals, Physical Properties, Organic Matter and Biochemistry

In general, the long term application of manure fertilizer increases the plant availability of some of the metals and has no effect on others. AB-DTPA extractable soil fractions and/or plant tissue content of copper, zinc, and cadmium may increase significantly with increasing manure or N fertilizer rates, but the increases are not large. Selenium, arsenic, and mercury plant availability generally remain unchanged by increasing manure fertilizer rates. Manure does not appear to enhance soil crust formation or interfere with emergence and early plant development, nor is it associated with significant increases in salinity, sodicity or soil strength. Repeated additions of swine manure had variable effects on soil organic

carbon in surface soils. Soils low in soil organic matter and of high clay content showed large, significant increases while soils high in organic matter did not show a significant effect. In some soils urea or swine manure addition may enhance the decomposition of soil organic matter. Increases in organic matter with cattle manure addition are attributed to direct addition of organic matter in manure. Increases in light fraction organic matter act as substrate for microorganisms to convert into stable humus.

Directions for Future Research: The time frame examined in this study represents the influence of five to eight years of manure application. As the life of an intensive livestock operation may be twenty years or more, it is important to continue to monitor the effect of manure application on key soil, crop and environmental quality parameters as measured in the current study. Furthermore, some of the properties change only very slowly over time, so an extended time frame of study is necessary to completely document the influence of repeated manure applications. There may be new strategies to better conserve and improve crop recoveries of manure nutrients that should be evaluated. For example, nitrification and urease inhibitors could be added to manure or manured soils that may reduce nitrogen losses and increase crop recovery.

Personnel

Dr. P. Qian, Research Officer part time
Mr. Corey Fatteicher, Research Technical Assistant
Mr. B. Feroglutak Laboratory Technican casual
Mr. M. Japp Graduate student full time
Ms. C. Stumborg Graduate student full time
Mr. T. King Graduate student (funded from Uof S scholarship)
Ms. S. Lipoth Graduate student (funded from CWB scholarship)

Equipment
none

Project Developed Materials 2003 and 2004

Scientific Papers, Book Chapters and Presentations

Assefa, B.A., J.J. Schoenau and M.C.J. Grevers. 2004. Effects of four annual applications of manure on Black Chernozemic soils. Canadian Biosystems Engineering 46: 39-46.

Qian, P., J.J. Schoenau, T. Wu and P. Mooleki. 2004. Phosphorus amounts and distribution in a Saskatchewan soil after five years of swine and cattle manure application. Canadian Journal of Soil Science 84: 275-281.

Mooleki, S.P., J.J. Schoenau , J.L. Charles and G. Wen. 2004. Effect of rate, frequency and incorporation of feedlot cattle manure on soil nitrogen availability, crop performance and nitrogen use efficency in east-central Saskatchewan. Canadian Journal of Soil Science 84: 199-210.

Schoenau, J.J., S.P. Mooleki, S.S. Malhi and G. Hultgreen. 2004. Strategies for maximizing crop recovery of nutrients applied as liquid swine manure. Great Plains Soil Fertility Conference Proceedings, Denver, CO. pp 8-14.

Schoenau, J.J. and J.G. Davis. 2004. Maximizing plant uptake and response to land-applied manure nutrients. Organic Waste to Resource Symposium. 68th Annual Soil Science Society of America Meetings, Seattle, WA, p. 140

Schoenau, J.J. and B. Assefa. 2004. Land application and handling of manure. In M. Amrani (ed), Manure Research Findings and Technologies: From Science to Social Issues pp 97-140. Edmonton, AAFRD Technical Services Division Press.

DeFrietas, J.R., J.J. Schoenau, S.M. Boyetchko and S.A. Cyrenne. 2003. Soil microbial populations, community composition and activity as affected by repeated applications of hog and cattle manure in eastern Saskatchewan. Canadian Journal of Microbiology 49: 538-548.

Wen,G., J.J.Schoenau, J.L. Schoenau and S. Inanaga, 2003. Efficiency parameters of nitrogen in hog and cattle manure in the second year following application. Journal of Plant Nutrition and Soil Science 166: 490-498.

Qian,P., J.J. Schoenau, T. Wu and S.P. Mooleki. 2003. Copper and zinc amounts and distribution as influenced by application of animal manure in east-central Saskatchewan. Canadian Journal of Soil Science 83: 197-202.

Schoenau, J.J., B. Assefa, M.Grevers, J. Charles, P. Mooleki, P. Qian and T. Zeleke. 2004. Manure management to improve soil quality. Proceedings of 2004 SSCA Direct Seeding Conference, Regina, SK. pp 105-111.

Schoenau,J.J. 2003. The role of manure as a nutrient in sustainable crop production. Future of Rural Peoples 5th International Symposium Abstracts, Saskatoon, SK. p. 6

Schoenau,J.J., B. Assefa, M. Grevers, J. Charles, S.P. Mooleki, P. Qian and T. Zeleke. 2003. The effects of manure on soil quality. Proceedings of Manure Management 2003 conference, Lethbridge, AB. pp 90-96.

Schoenau, J.J., S.P. Mooleki, P. Qian and S.S. Malhi. 2003. Balancing the availability of nutrients in manured soils. Proceedings of Focus on the Future Conference: Optimizing Production Systems, Saskatoon, SK. pp 64-68.

Mooleki, P., J.J. Schoenau, T. King and G. Hultgreen. 2004. Soil and canary seed yield response over three years to a single application of poultry manure on a heavy clay soil near Regina, SK. Proceedings of 2004 Soils and Crops Workshop , Saskatoon, SK (On CD).

King, T., J.J. Schoenau, M. Grevers, S.S. Malhi and G. Hultgreen. 2004. Surface soil nutrient contents and crop yields after five to seven annual applications of manure. Proceedings of 2004 Soils and Crops Workshop , Saskatoon, SK (On CD).

Japp, M. , J.J. Schoenau, M. Grevers and L. Bohrson. 2004. Soil conditions and early plant growth as influenced by repeated manure applications. Proceedings of 2004 Soils and Crops Workshop , Saskatoon, SK (On CD).

Lipoth, S. and J.J. Schoenau. 2004. Impact of repeated manure applications on trace metal load and plant availability in Saskatchewan soils. Proceedings of 2004 Soils and Crops Workshop , Saskatoon, SK (On CD).

Qian, P. and J.J. Schoenau. 2004. Influence of manure application on extractable potassium in a range of prairie soils. Proceedings of 2004 Soils and Crops Workshop , Saskatoon, SK (On CD).

Mooleki, S.P. , J.J. Schoenau, S.S. Malhi and S. Brandt. 2003. Soil and crop responses to injected liquid swine manure in two gray luvisols. Proceedings of 2003 Soils and Crops Workshop , Saskatoon, SK (On CD).

Qian, P., J.J. Schoenau, T. Wu and S.P. Mooleki. 2003. Impact of repeated addition of swine and cattle manure on soil copper and zinc in a Saskatchewan soil. Proceedings of 2003 Soils and Crops Workshop , Saskatoon, SK (On CD).

Schoenau, J.J., S.P. Mooleki, P.Qian and S.S. Malhi. 2003. Balancing the availability of nutrients in manured soils. Proceedings of 2003 Soils and Crops Workshop , Saskatoon, SK (On CD).

J.J. Schoenau. 2004. Manure constituents and their impact on soils and crops. Saskatchewan Manure Management Conference, June 15, Saskatoon, SK.

J.J. Schoenau and T. King. 2004. Manure management to minimize environmental impacts. North Saskatchewan River Watershed Management Planning Meetings, April 7, North Battleford, SK. and July 22, Saskatoon, SK.

J.J. Schoenau. 2004. Value of manure and its impact on soils and crops. SAFRR Manure Management Seminar, March 12, Yorkton, SK.

J.J. Schoenau. 2004. Soil and crop responses to swine manure in the Gray soil zone. Melfort AAFC Field Day, July 16, 2003, Melfort

J.J. Schoenau. 2003. Swine manure management. SAFRR Livestock Production and Manure Management Tour 2003. July 8, 2003, Humboldt.

J.J. Schoenau. 2004. Best manure management practices. Melfort AAFC Field Day July 19, Melfort and Indian Head AAFC Field Day July 20, Indian Head.